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BOSTON

CONTRIBUTIONS

FROM THE

SANITARY RESEARCH LABORATORY

AND

SEWAGE EXPERIMENT STATION

VOL. II

Purification of Boston Sewage

History of the Sewage Disposal Problem

WATER SUPPLY AND IRRIGATION PAPER No. 185
U. S. GEOL. SURVEY

H.T. Letton

Water-Supply and Irrigation Paper No. 185 Series L, Quality of Water, 15

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

(2 - 3)

INVESTIGATIONS
ON THE
PURIFICATION OF BOSTON SEWAGE

Made at the Sanitary Research Laboratory and Sewage Experiment Station
of the Massachusetts Institute of Technology

WITH A

HISTORY OF THE SEWAGE-DISPOSAL PROBLEM

BY

C.-E. A. WINSLOW AND EARLE B. PHELPS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1906

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INVESTIGATIONS ON THE PURIFICATION OF BOSTON SEWAGE.

By C.-E. A. Winslow and Earle B. Phelps.

INTRODUCTION.

By William T. Sedgwick.

Systems of water carriage, or sewerage, are now almost universally employed for the quick and inoffensive removal of fluid wastes and human excrements from thickly settled communities. These fulfill fairly well that first and most imperative requirement of scientific sanitation—the prompt and efficient removal of the more dangerous excreta. As often happens, however, the solution of one problem has given rise to another scarcely less difficult, namely, in this case, the sanitary and economic disposal of vast quantities of contaminated liquids known as sewage. The volumes of sewage discharged by modern communities are so large, especially in the United States, where water is liberally supplied, freely used, and frequently wasted, and the character of all kinds of sewage is always so objectionable, that the so-called sewage-disposal problem becomes, from the economic as well as the sanitary point of view, one of the most serious with which modern communities have to deal. Nor is this merely a public or community problem. Isolated private houses of the better class are now almost invariably abundantly fed with running water—a supply which has become one of the greatest necessities as well as one of the greatest luxuries of civilized life. In such houses the water-carriage system for the disposal of household wastes of all kinds has found favor no less than in crowded communities. Here, also, it entails a difficult problem, i. e., the ultimate disposal of large quantities of noxious sewage; and for the house no less than for the community it is important to secure this ultimate disposal in such a way as to avoid the creation of any insanitary focus or foci in the environment, or any infringement of the laws of hygiene and sanitation.

Moved by the magnitude and gravity of the sewage-disposal problem as it concerns householders and communities, an anonymous friend of the Massachusetts Institute of Technology, in 1902, presented to that institution the sum of $5,000 a year for three years, for the purpose of making experiments on sewage purification and of giving the widest possible publicity to means or methods by which the present too often crude and imperfect systems may be improved. In a letter which constituted a virtual deed of gift, the donor designated a preference for the following lines of activity:

1. For keeping up with the investigations of the best workers in all countries.
2. For utilizing this knowledge in the work of the Massachusetts Institute of Technology.
3. For original experiments.
4. For distributing all over the country the results of the work in such words that he who runs may read.
5. For inciting students to make plain and simple statements of the results of their studies.

The gift thus made was gratefully accepted by the authorities of the Massachusetts Institute of Technology, and the planning and organization of the work to be done were assigned by them to the writer, head of the department of biology, who had for some years served as lecturer in the Institute on sanitary science and public health, and had also gained considerable experience in sewage purification during a connection of several years with the work of the State board of health of Massachusetts. In view of the limited means available and the long-continued and well-known investigations of the Massachusetts State board of health at the Lawrence experiment station, dealing chiefly with the sewage of an inland city; in view, also, of the increasing use of harbors for the disposal of the sewage of seaboard towns, with the growing dangers of contamination of shellfish, pollution of bathing beaches, and the like; and especially in view of the desirability of making the new work of practical educational value to the students of the Institute of Technology, who might carry away with them into active life and to all parts of the country the results of personal knowledge of the work, it was decided to establish a sanitary research laboratory and sewage experiment station on the main trunk sewer of the south metropolitan system of the great seaboard city of Boston. The precise point finally chosen, near the corner of Massachusetts avenue and Albany street, has proved very convenient and favorable. Here a piece of land formerly occupied by a livery stable was secured on a long lease, the stable itself was turned into a tank house, and a smaller building on the premises was fitted up as an office, with chemical and bacteriological laboratories connected. Open space enough remained for the construction later of outdoor filters and a large trickling filter. Permission was obtained for making connections with the main trunk sewer of the south metropolitan system on its way to the sea at a point where it contained the sewage of a contributing population of about half a million people, and for drawing sewage from this sewer as needed. A pump was installed, tanks were constructed for tests of various methods of sewage purification, and a working organization was effected by the formal appointment of the writer as director, of C.-E. A. Winslow as biologist in charge of the laboratory and station, and of Earle B. Phelps, a graduate of the Institute in the department of chemistry, and for some years assistant at the Lawrence experiment station of the Massachusetts State board of health, as research chemist and bacteriologist. A full description of the laboratory and experiment station is given on pages 97–107, illustrated by figs. 10–14.

The elaborate and long-continued experiments of the State board of health of Massachusetts at the Lawrence experiment station on intermittent sand filtration as a means of sewage purification made it advisable to set up only three filters of this kind, largely for demonstration purposes and for the benefit of students. To the so-called septic-tank method it was felt necessary to give somewhat more attention, the value of this process under various conditions being still somewhat problematical; and to the contact system much attention was given for the same reason. More recently, continuous filtration by means of trickling filters has come to the front, particularly in England, and this system of disposal has therefore required especially careful consideration and study.

As a prerequisite for all these investigations it was plainly necessary to make, in the first place, careful examinations of the character and amount of the sewage actually discharged by the south metropolitan system of Greater Boston. The results of these examinations have already been published, together with other papers, in vol. 1 of "Contributions from the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology," of which the present work is volume 2. Volume 1 appeared originally in the "Journal of Infectious Diseases," volume 1, supplement No. 1, Chicago, 1905, and was also reprinted as a separate brochure. This latter was in large demand and is now unfortunately out of print, but a limited number of the copies of the "Journal of Infectious Diseases" containing these papers may still be purchased from the publishers. As a matter of record the titles of the papers may here be given, as follows:

The chemical and bacterial composition of the sewage discharged into Boston Harbor from the south metropolitan district. C.-E. A. Winslow and E. B. Phelps.

The number of bacteria in sewage and sewage effluents determined by plating upon different media and by a new method of direct microscopic enumeration. C.-E. A. Winslow.

The mode of action of the contact filter in sewage purification. E. B. Phelps and F. W. Farrell.

A critical study of the methods in current use for the determination of free and albuminoid ammonia in sewage. E. B. Phelps.

The determination of the organic nitrogen in sewage by the Kjeldahl process. E. B. Phelps.

Test of a method for the direct microscopic enumeration of bacteria. C.-E. A. Winslow and G. E. Willcomb.

The present volume contains, first, a careful and elaborate historical review of the whole sewage-disposal problem from its origin in the wide adoption of the water-carriage system up to the present time, when that system has become practically universal. This interesting review can not fail to be of the highest value to expert engineers, sewage commissioners, and communities all over the United States, especially those numerous small communities which are confronted, perhaps for the first time, with a problem which means so much for the health as well as the finances of the citizens.

Following the historical review is a full description of the experiments thus far made on the sewage of a great American seaboard city, together with comparisons with similar work done elsewhere, with practical conclusions which have been drawn from the experiments and specific statements concerning the comparative merits of various systems of purification tested. These are by no means applicable merely to large cities or to seaboard cities, but contain lessons of practical value for all sorts of communities having to deal with the ever present sewage-disposal problem.

This report is by no means final, for experiments are still in progress not only along these lines but also along others more recently developed. In particular, the percolating, trickling, or continuous filter method is being more extensively tested, with results which it is hoped may be ready for publication by the end of another year.

The donor of the original gift has consented to continue the work for the fourth and fifth years—an immense advantage in work of this kind, which grows in interest and value with the lapse of time as well as with the experience gained by the workers on the problems involved. In consonance with the wishes of the donor as expressed in the deed of gift, it is the intention of the director to prepare a brief popular statement of the facts contained in this volume, in language so simple that citizens, boards of health, and sewerage commissions may readily avail themselves of the information here contained, and so that, as desired by the donor, "he who runs may read."

The work here described and the results here recorded have no connection with the well-known work of the State board of health of Massachusetts and no official connection with the city of Boston or any of its departments. They proceed entirely from an educational institution—the Massachusetts Institute of Technology—and all the officers and workers at the laboratory and station have been either officers, graduates, or students of the Institute.

If, however, as is quite within the bounds of possibility, it should ever become necessary to purify the sewage of Greater Boston, or of any part of it, before discharging it into the waters of Boston Harbor, there is reason to believe that these studies may have a practical local value in proportion to their cost. Meantime, it is the wish of the director no less than of the donor that they may be found immediately serviceable to numerous American communities confronted with the sewage-disposal problem and seeking means for its solution.

In addition to those persons already mentioned, the working staff of the laboratory and station has included, for longer or shorter periods, Prof. S. C. Prescott, of the Massachusetts Institute of Technology; Prof. E. G. Smith, of Beloit College; Miss Anne F. Rogers, and Messrs. George R. Spalding, Frederick W. Farrell, George C. Bunker, George E. Willcomb, James A. Newlands, William H. Beers, and William T. Carpenter, all of whom have contributed directly or indirectly to the discussions and results contained in this volume.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
Boston, April, 1906.

HISTORY OF THE SEWAGE-DISPOSAL PROBLEM.

NATURE OF THE PROBLEM.

The disposal of waste is a fundamental problem for all living organisms. As the body takes in food and builds it up into its own peculiar structure, so it must continually break down and give off waste products, which, as a rule, if they accumulate, prove poisonous to the organism itself. This is the case with the individual; it is still more the case when large numbers of organisms are closely congregated together in communities. The political body resembles the organisms of which it is composed in no merely fanciful sense. It is subject to the laws of organic life; it has its income and its outgo; and a failure to remove the waste products of its life processes is inevitably dangerous to the units of which it is composed.

In spite of these facts, the attempt at scientific waste disposal is comparatively recent. The Cloaca Maxima and the other so-called sewers of antiquity were rather drains than sewers, and their function was to lower the ground-water level and not primarily to remove excretal wastes. Until 1815 the discharge of any waste but kitchen slops into the drains of London was prohibited by law, and the same regulation persisted in Paris up to 1880. Sewerage and sewage disposal proper really date from the epoch-making report of the health of towns commission of Great Britain in 1844,[a] which revealed the accumulation of such an astonishing amount of decomposing organic matter and filth of all kinds in the cities that it aroused British sanitarians to a strong movement for the amelioration of these conditions and led to the development of the filth theory of disease—the theory that disease is bred in heaps of decomposing filth. This pythogenic theory of Chadwick and Murchison we now know to be wrong in its essential assumption that infective material is created de novo by decaying organic matter; yet it was right in laying emphasis on filth as a carrier of disease. The wonderful administrative work of the British sanitarians, acting on this partially erroneous theory, effected the greatest sanitary progress which has probably ever been known. Public and private cleanliness was taught and practiced as never before. The midden system and the pail system rapidly gave way to the water-carriage system. Whereas in 1815 the sewers of London were simply drains to carry off the storm water—the discharge of sewage into them being forbidden by law—in 1847, only three years after the report of the health of towns commission, it was made obligatory to discharge all sewage into those drains.

In other countries the example set in England was more or less promptly followed. In the United States numerous drainage systems existed, one in Boston, for example, dating from the seventeenth century; but the first comprehensive sewerage project was designed by E. S. Chesbrough for the city of Chicago in 1855. On the continent of Europe a sewer system was constructed at Hamburg after the great fire of 1842, by Lindley, an English engineer. Berlin began her sewerage in 1860 and other German systems quickly followed. France and the Latin countries, though still somewhat inadequately sewered, are making progress. No law of sanitation is now more clearly recognized than the principle that the wastes of human life must be diluted with an adequate supply of water and quickly removed from the region of habitation.

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[a] Frequent reference will be made to the investigations of the royal commissions of Great Britain, and in order to avoid confusion the following chronological summary of the work of those commissions which have dealt with sewage disposal and allied subjects is quoted from A. J. Martin:

1843. Royal commission appointed "to inquire into the present state of large towns and populous districts" (health of towns commission).
1844. First report of health of towns commission.
1845. Second and final report of health of towns commission.
1857. Royal commission appointed to inquire as to the best means of distributing the sewage of towns (sewage of towns commission).
1858. Preliminary report of sewage of towns commission.
1861. Second report of sewage of towns commission.
1865. Commission appointed to inquire in the best means of preventing the pollution of rivers (rivers pollution commission).
Third report of sewage of towns commission.
1868. Second rivers pollution commission appointed.
1870. First and second reports of rivers pollution commission.
1871. Third report of rivers pollution commission.
1872. Fourth and fifth reports of rivers pollution commission.
1874. Sixth and final report of rivers pollution commission.
1882. Commission appointed to inquire into the effects of the discharge of the sewage of the metropolis into the river Thames (metropolitan sewage commission).
1884. First report of metropolitan sewage commission.
1885. Second and final report of metropolitan sewage commission.
1898. Commission appointed to inquire and report what methods of treating and disposing of sewage may properly be adopted (royal sewage commission).
1901-2. Interim report of royal sewage commission.
1902. Second report of royal sewage commission.
1903. Third report of royal sewage commission.
1904. Fourth report of royal sewage commission.

With the establishment of the water-carriage system the difficulty was shifted from the individual to the community. The insanitary conditions surrounding the dwelling were relieved, but at some point on the outskirts of the city the concentrated filth from its entire population must be disposed of. The vast volume of water in which the excretal elements are distributed makes the problem only more difficult. In England the average daily flow of sewage is about 25 gallons per capita. In London it is 34 gallons (R. S. C., 1902 b[a]). In the United States, on the other hand, the flow in several small Massachusetts cities is estimated at about 100 gallons (Fuller, 1903), while for the south metropolitan district of Boston it is over 250 gallons (Winslow and Phelps, 1905). In the latter case the yearly flow of sewage amounts to 46 billion gallons—a fair-sized river. The organic matter to be treated includes during the year over 1,500,000 kilograms of nitrogen in the form of free ammonia alone. The treatment of such a volume of waste material offers a problem in applied chemistry of no mean magnitude.

The undesirable constituents in sewage may be considered under two heads—living germs and dead organic matter. The first create disease; the second breeds nuisances. The germs of almost any disease of man or the lower animals may gain access to sewage, and, in the case of typhoid fever in particular, the infection may be transmitted through its agency so as to cause epidemics on a disastrous scale. The experiments of Jordan, Russell, and Zeit (1904) and of Frost (1904) indicate that typhoid bacilli in water, and particularly in sewage-polluted water, for the most part die in a few days. Yet the statistics of Lowell, Lawrence, Chicago, Philadelphia, Pittsburg, and Newark indicate that the typhoid germs which survive a sojourn in sewage and water are sufficiently numerous to produce serious results. Therefore where shellfish are taken from an estuary into which sewage is discharged it is desirable to subject the sewage to some process—such as sand filtration—which effects a considerable reduction in bacterial content; and the sterilization of an effluent after its complete oxidation might, under certain conditions, prove desirable. As a rule, however, if the effluent from a sewage plant as discharged into a stream is clear and nonputrescible, the process is considered to be satisfactory. It is becoming more and more clearly recognized that all polluted waters, perhaps all surface waters, should, before they are used for drinking, be treated by water filters designed for the special purpose of removing disease germs. If such filtration as this is to follow, it is unnecessary to place on the sewage-purification works the extra burden of bacterial removal. The immediate and pressing need at the sewer outfall is the disposal of the organic matter, which threatens to create a nuisance by its decomposition. This organic matter may often be rendered harmless by means quite different from those calculated to effect high bacterial removal. When such is the case, it is scarcely fair to hamper the essential task of sewage disposal by demanding a bacterial purification which can be better attained by subsequent special treatment in water filters. All sewage-purification processes, as a matter of fact, materially reduce the number of bacteria present; but this must in general be regarded as incidental, the success of the process being gaged chiefly by the fate of the organic matter.

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[a] Complete references to all literature cited in this report will be found in the bibliography at the end. References in the text include the name of the authority (the initials in the case of the British commissions) and the date of publication, with a distinguishing letter in case more than one volume appeared in a single year. This serves simply to identify the article or book, the full title of which is given in the bibliography.

Where the waste from manufacturing processes is abundant, certain special problems are introduced. The material to be handled may be greatly increased in amount and the added material may be organic matter of a specially refractory kind, such as is found in wool-scouring waste, tannery waste, and brewery waste. Furthermore, the presence of mineral poisons may interfere with the very processes which bring about the purification of the organic matter present. The acid-iron sewage of Worcester is an example of this sort, the biological processes of purification being appreciably hampered by the waste liquors from wire mills. The waste from the sulphite-pulp mills offers a notable example, carrying vast amounts of refractory organic matter, together with antiseptics which prevent any bacterial treatment until they are removed. Such industrial wastes require specific treatment in each case, generally along mechanical and chemical lines. They offer special problems quite distinct from the main question of sewage treatment, to which it is desired to limit the present paper.

In the disposal of ordinary domestic sewage it is primarily dead organic matter which must be dealt with. The products of the metabolism of men and animals and the partially decomposed waste materials from the preparation of food are largely made up of unstable organic compounds. They must be further decomposed, and the decomposition may follow either of two different courses. Under ordinary conditions a rapid reduction of any available oxygen first takes place, followed by an incomplete anaerobic putrefaction, accompanied by the evolution of methane, carbon dioxide, nitrogen, hydrogen, and various ill-smelling gases, such as hydrogen sulphide and the mercaptans. Such a process is likely to create a nuisance objectionable from economic as well as esthetic grounds. The odors of decomposition may even become so objectionable as to menace the public health.

The history of the organic matter is quite different if its decomposition takes place in the presence of an abundant supply of oxygen. If dry organic matter is burned, it is converted into water and the oxides of carbon and nitrogen. If moist organic matter is allowed to ferment in the presence of an ample supply of oxygen, a slow oxidation is accomplished by the activity of certain micro-organisms, and the end products are again water, carbon dioxide, and nitrates. This aerobic fermentation is free from odor, and its end is the complete conversion of the decomposition products into harmless inorganic constituents. Such an oxidation alone can finally dispose of the excretal products and prevent the obnoxious conditions attendant on anaerobic putrefaction. This is the rational aim of all processes of sewage disposal, which may be defined as methods for the conversion of the waste products of organic life and death into their oxidized and mineral forms.

COMPOSITION OF SEWAGES.

Chemically considered, sewage is a dilute solution and suspension of certain organic and inorganic substances in water. The statement, originally made in 1890 by Hiram F. Mills and often quoted by subsequent writers, that "a sewage stronger than ordinary would contain, say, 998 parts of pure water, 1 part of mineral matter, and 1 part of animal and vegetable matter," serves its intended purpose in fixing an upper limit for the constituents of sewage, but is excessive for the sewage of American and English cities in its estimate of solids. From the data available it may be stated that 800 parts per million of total solids, as against 2,000 parts given by the standard mentioned, is a liberal figure for American cities and is exceeded by few; English cities may average about twice as much, while the continental European cities vary widely, but in few cases exceed 2,000 parts.

Of the total solids in a sewage it may be said roughly that from 60 to 70 per cent is in solution, either true or colloidal, the remainder being insoluble matter in suspension. Measured by the nature of the solids, about one-half, as a rule is volatile on ignition, representing in the main organic matter, while the remainder, called the fixed solids, represents the mineral matter originally present, as well as the mineral ash of the organic matter. The fact should be emphasized in this connection that many mineral substances are lost on ignition and that the combustion of nearly all organic substances occurring in nature leaves a greater or less amount of mineral ash. By far the larger part of the fixed solids is found dissolved, this amount on the average reaching about 75 per cent of the total, most of the remainder being sand or other insoluble matter, largely derived from street washings. The division of the organic matter is about equal between dissolved and suspended matter.

Concerning the character of the mineral matter present, it may be said that the portion in solution is of little consequence in relation to sewage treatment. It consists largely of sodium chloride. In certain special cases dissolved mineral matter may be precipitated during treatment and become burdensome. This is especially the case where iron salts are present in considerable amount. The insoluble mineral matter and the mineral residue from organic matter concern the present discussion more immediately, since in many processes of treatment these materials will accumulate to the detriment of filters. They normally amount to perhaps 10 per cent of the total solids and in the case of cities sewered on the separate system will not vary materially from that proportion. Combined sewers, however, admitting storm water from the streets, deliver an immense amount of sand and similar material during a storm, for the care of which some provision must be made at the disposal plant. No estimate can be made of the amount of such material likely to be delivered. It will depend entirely on local conditions, especially on the nature of the streets and the soil and on the severity of storms.

The character of the organic matter is of much greater importance. It is customary to speak of nitrogenous and carbonaceous matter, although the nitrogenous matter contains as a rule more carbon than nitrogen. Since, however, organic matter containing nitrogen gives rise on decomposition to products offensive to the senses, and since the various products of its oxidation are readily determined by simple analytical methods, much greater stress has always been laid on the nitrogen in sewage than on any other element. The total nitrogen value for American city sewages may be roughly placed at from 15 to 35 parts per million. Of this amount from one-third to one-half, depending on the condition of the sewage, will be in the form of free or saline ammonia, largely as ammonium carbonate. The remainder, say from 10 to 25 parts per million, exists in combination as organic nitrogen. The nitrogenous organic material present in part results from the breaking down of proteid or albuminous material in digestion and in part represents unaltered proteid material. Albumin contains about 16 per cent of nitrogen, while its decomposition products—leucine, tyrosine, and various other amido-acids—

contain from 8 to 10 per cent, so that 10 per cent may perhaps be taken as an average value for the nitrogen in the nitrogenous material. This gives an amount of such material equal to from 100 to 250 parts per million in the sewages under discussion. Roughly, about one-half of this nitrogenous material is carbon in organic combination, giving from 50 to 125 parts per million of carbon. The total carbon of such sewages may be expected to be between 100 and 300 parts, say 200 for an average, of which perhaps 75 parts are found in the nitrogenous material. This leaves 125 parts of carbon as carbonaceous (nonnitrogenous) material, of which the greater part is cellulose or some other carbohydrate and fat. From the rather meager data available as to the amount of fat in sewage, it may be concluded that 50 parts per million is perhaps a fair average figure. Seventy per cent of the fat, or 35 parts, is carbon, which, deducted from the 125 parts previously mentioned, leaves about 90 parts of carbon as carbohydrate. The proportion of carbon in carbohydrates being taken at 46 per cent, this gives 200 parts per million of carbohydrate. The figures thus deduced may be taken as fair average figures for American sewages. Considerable variation from the estimates may be found, amounting to perhaps 50 per cent on either side, but the relative amounts seem to be fairly constant as far as can be judged from available data. For the sake of clearness these typical figures are tabulated below:

Composition of an ideal sewage.

[Parts per million.[a]]

	Total.	In solution.	In suspension.
Residue on evaporation	800	500	300
Mineral and ash	400	300	100
Organic and volatile	400	200	200
Nitrogenous	150		
Nitrogen	15		
Carbon	75		
H, O, S, P, etc	60		
Nonnitrogenous	250		
Fats, etc	50		
Carbon	35		
H, O	15		
Carbohydrates	200		
Carbon	90		
H, O, etc	110		
Total carbon	200		
Total nitrogen	15		
Total H, O, S, P, etc	185		

[a] All analytical results in this report are expressed in parts per million. Data cited from other authorities have been converted to the same basis.

In order to change these figures to grams per capita per day it is only necessary to multiply by 0.38, a daily flow of 100 gallons per capita being assumed.

The sewage of English cities is in general stronger than the figures given here for a typical American sewage. Analyses previously compiled (Winslow and Phelps, 1905) indicate that the total solids in

European sewages will average about 1,500 parts per million, with a range of from 500 to 2,100 parts. The organic constituents also, as measured by total organic nitrogen, indicate that European sewages are twice as strong as American. Values for oxygen consumed are not comparable on account of differences in analytical methods, but those for free ammonia are much more nearly equal in the two cases.

The amount of oxygen required to convert these organic substances into the mineral form is considerable. Dibdin, as shown in Table I, estimates it at from one to three times the weight of the organic substance to be acted on.

Table I.—*Parts of oxygen required to oxidize one part of various organic substances (Dibdin, 1903).*

Substance.	Oxygen required.				Oxygen already present.	Difference, or additional oxygen required for complete oxidation.
	By the nitrogen.	By the hydrogen.	By the carbon.	Total.		
Gelatin	0.523	0.528	1.333	2.384	0.251	2.133
Chondrin	.411	.568	1.310	2.289	.294	1.995
Albumen	.457	.568	1.414	2.439	.220	2.219
Cellulose, woody fiber		.496	1.184	1.680	.494	1.186
Starch		.496	1.184	1.680	.494	1.186
Fat, stearic acid		1.016	2.025	3.041	.113	2.928

The problem of sewage disposal is to supply this required oxygen and to supply it under such conditions that it will unite with the organic matter to be eliminated.

DISPOSAL OF SEWAGES BY DILUTION IN LAKES, RIVERS, AND THE SEA.

The most obvious way to dispose of sewage is to empty it into the nearest body of water. Before true sewers existed the natural drains discharged into the nearest watercourse, and when the drains became filled with polluting matter the same plan was followed. Within certain limits the process proved a success. When the volume of sewage was not too great it disappeared by dilution and was finally removed by the agencies involved in the "self-purification of streams." The dilution is, of course, only an aid to purification and not in itself an active agent in the process. A drop of ink in a barrel of water is still existent, though invisible. Sedimentation, too, is scarcely in itself a process of purification, although it performs a most important part, separating the solids and storing them so that other agencies may have time to act. Oxidation of the organic matter is the real purification process, and it is by virtue of this process that streams are able to dispose of organic pollution when they do so successfully.

The oxidation of organic matter in a stream or pond may be partly due to direct chemical action. In the main, however, it is carried out by the activity of micro-organisms. The larger microscopic forms, the crustacea, the rotifera, and the protozoa, play a part the exact importance of which is hard to estimate, especially in the consumption of the solid particles. The algæ and other green plants exercise an important influence, as shown by Bokorny (1897) and others. The chief agents, however, are the bacteria, particularly those metatrophic and prototrophic forms which liquefy proteids, liberate free ammonia from more complex compounds, and oxidize it to the mineral form.

The process of self-purification of streams, though a real process, is a slow one. The rivers pollution commission of Great Britain concluded in 1874 that sewage mixed with twenty times its volume of pure water would be two-thirds purified in flowing 168 miles at a rate of 1 mile an hour. Long, in 1889, made a careful study of this process in the Illinois and Michigan Canal. A large part of the sewage of Chicago, diluted with the water of Lake Michigan, at that time flowed through the canal for a distance of 29 miles at a rate of about 1 mile an hour. Analyses from Bridgeport and Lockport, at the beginning and end of the canal, as shown in Table II, gave a purification of 23 per cent as measured by albuminoid ammonia and 27 per cent measured by oxygen consumed, with a removal of 46 per cent of the matter in suspension.

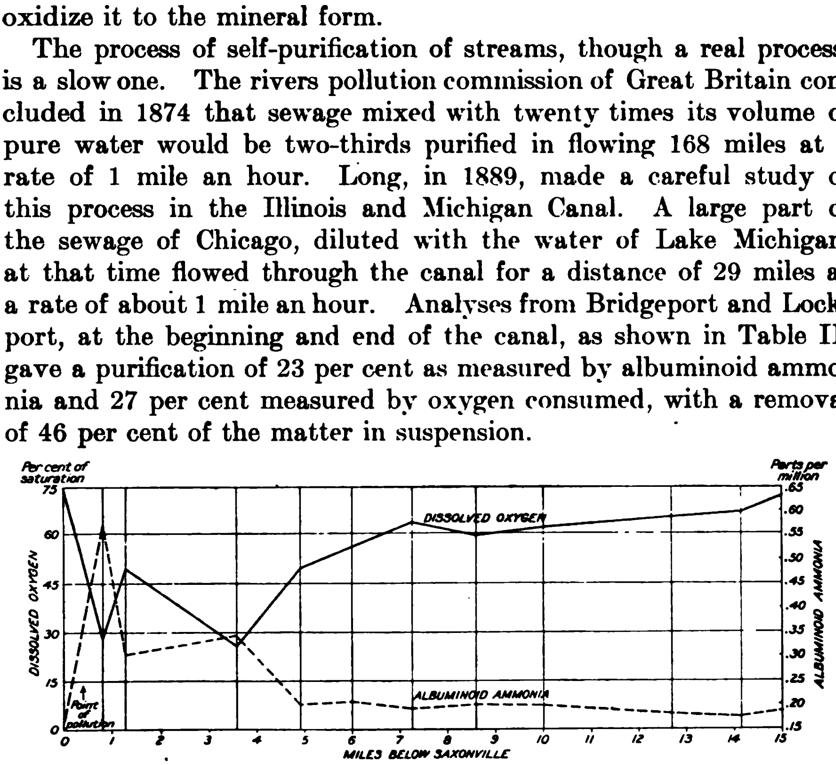

FIG. 1.—Diagram illustrating self-purification of Sudbury River.

TABLE II.—*Analyses of water from the Illinois and Michigan Canal at Bridgeport and Lockport (Rafter and Baker. 1894).*

[Parts per million.[a]]

Place collected.	Total solids.	Matter in suspension.	Nitrogen as nitrates.	Chlorine.	Hardness ($CaCO_3$).	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Oxygen consumed.
Bridgeport	471.2	129.2	0	46.8	201.3	10.1	2.1	22.1
Lockport	431.2	69.8	0	46.1	207.7	8.9	1.6	16.2

[a] Free and albuminoid ammonia values throughout this paper are expressed as nitrogen. The method by which oxygen-consumed determinations were made is stated whenever it could be ascertained from the original reports.

Streams with more sluggish flow will naturally exhibit a greater purification in a short distance, since sedimentation will be greater and since the time during which the nitrifying organisms act is one of the chief factors involved. Sudbury River in Massachusetts, for example, is heavily polluted at Saxonville by the wastes from a woolen mill. It flows rapidly for about 3 miles below the mill and then enters an area of meadows where it winds along through a weedy channel at a rate not more than one-fourth mile an hour. In an investigation by Woodman, Winslow, and Hansen (1902) it was found that 3 miles below the entrance to the meadows and 6 miles below the mill the chemical constituents of the stream had fallen to their normal. The relations of albuminoid ammonia and dissolved oxygen on one of the days studied is indicated in fig. 1, in order to illustrate the progress of the purifying process. It will be noticed that below the point marked "Point of pollution" the albuminoid ammonia is greatly increased, and the dissolved oxygen, being absorbed by the organic matter, is correspondingly diminished. Gradually, however, normal conditions reassert themselves, more oxygen is absorbed, and the albuminoid compounds settle out and are oxidized. At the station 6 miles below the point of pollution both constituents have been restored to their original value. Throughout, the reciprocal variation of the oxygen and the oxidizable nitrogen are striking.

Next to the time element the amount of available dissolved oxygen is, as this diagram suggests, the chief condition for the purification process; and the whole history of the pollution and self-purification of streams may be traced by the diminution and gradual restoration of this constituent. Dibdin's studies of the Thames below London are most significant in this respect and illustrate on a practical scale the enormous volumes of the oxidizing agent needed. He estimates (Dibdin, 1904) that 2,000 tons of oxygen are absorbed by the river between Teddington and Southend in this process. The proportion of dissolved oxygen, expressed as "Per cent of saturation," at various points along the river on the high tide is plotted in fig. 2 from figures given by Dibdin (1904) for 1893–94. As the river enters the city between Kew and Battersea its oxygen content falls from 70 per cent to 43 per cent, and the progressive pollution continues until at Woolwich the oxygen value is only one-fifth that of saturation. Below Barking Creek the heavy pollution ceases, absorption of oxygen overbalances its consumption, and the normal conditions are gradually restored. The same general relations are shown in Table III, quoted by the Connecticut State sewage commission (1899). The ratio of oxygen to nitrogen, which changes from 1:2 at Kingston, above London, to 1:62 at Greenwich, is most significant.

TABLE III.—*Dissolved gases in the Thames above and below London, England (Connecticut, 1899). Analyses by Roscoe and Schorlemmer.*

[Cubic centimeters per liter.]

	Kingston.	Hammer-smith.	Somerset House.	Green-wich.	Wool-wich.	Erith.
Total volume of gas	52.7		62.9	71.25	63.05	74.3
Carbon dioxide	30.3		45.2	55.6	48.30	57.0
Oxygen	7.4	4.1	1.5	.25	.25	1.8
Nitrogen	15	15.1	16.2	15.4	14.5	15.5
Ratio of oxygen to nitrogen	1:2	1:3.7	1:10.8	1:62	1:58	1:8.6

When in any river the proportion of organic matter is slightly increased over that in the Thames at Woolwich, the small proportion of dissolved oxygen may be quite consumed. Conditions change and instead of aerobic nitrification, anaerobic putrefaction is set up. Foul-smelling gases are produced, and in place of a self-purifying stream a septic tank or open cesspool is produced.

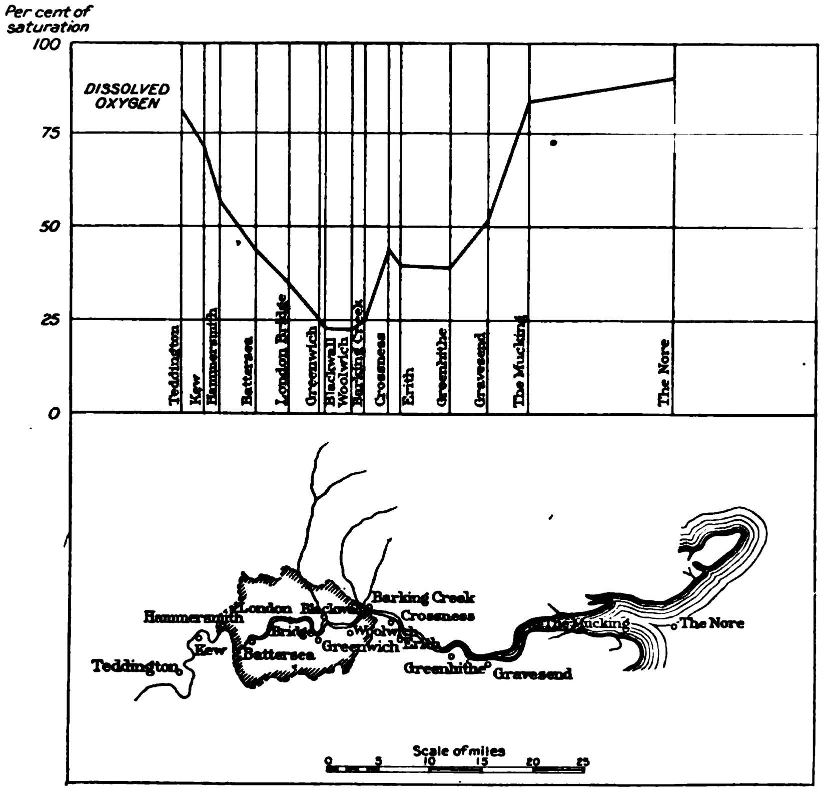

FIG. 2.—Diagram illustrating self-purification in the Thames, England.

There is evidently a critical point in the purification of sewage by discharge into water. Up to a certain point the organic matter is successfully nitrified. As soon, however, as the material to be oxidized exceeds the available oxygen, aerobic purification stops and putrefaction takes its place. Rideal has attempted to express the relation between the various factors involved in the form of an equation, $XO = C(M - N)S$, where X = flow of a stream, O = parts of dissolved oxygen in the water of the stream per unit flow; S = volume of sewage or effluent; M = parts of oxygen consumed by a unit volume of sewage; N = parts of available oxygen in the form of nitrites and nitrates, and C = a constant. When the available oxygen exceeds the demand all goes well; when it does not, trouble ensues.

The ocean furnishes seaboard cities with the most favorable possible conditions for disposal in water. At New York and many other places small sewers discharge at frequent intervals into tide water. In Boston this method caused a serious nuisance, and as a result a somewhat more elaborate system was begun in 1876. Since 1895 two main sewers have discharged into the harbor, serving the city and surrounding metropolitan district, which includes 25 cities and towns with a territory of nearly 200 square miles. The sewage of the region north of the Charles flows continuously from an outlet near Deer Island Light and amounts to about 50 million gallons per day. The sewage from the region south of the Charles, averaging in 1904 100 million gallons per day, has been discharged since 1884 at Moon Island, nearer the center of the harbor. Here, in order to protect the adjacent shores, it has been thought necessary to hold the sewage in four masonry basins and to discharge it only on the outgoing tide. September 19, 1904, a third outlet was opened to take the sewage from certain high-level regions in the south metropolitan district. This discharges continuously in the outer harbor near Nut Island and delivers 20 million gallons per day, leaving the diminished flow at Moon Island about 80 million gallons. Experience has shown that no serious nuisance is caused by the Deer Island and Moon Island outlets. The sewage in the first case disappears within 1¼ miles of the outlet, while off Moon Island the sewage stream may be traced outward round the south end of Long Island for perhaps 2 miles. In both cases passing boats find the immediate vicinity of the outlet unpleasant, and near Moon Island the value of property on the mainland is said to be affected. No serious menace to health, however, is involved. The sewage apparently produces no permanent damage in the harbor, and recent investigations carried out by J. H. McManus and A. W. Walker in the laboratories of the Massachusetts Institute of Technology indicate that even in high winds there is no tendency for sewage bacteria to be carried into the air and blown shoreward. So popular is the method of disposal in the sea that according to a review made by the Massachusetts State board of health in 1902

(Massachusetts, 1903) nearly one-half the population of that State is tributary to such systems. In general they have proved successful, although a serious nuisance is created in some places, as at Lynn, where the sewage is discharged in shallow water and over tidal flats. In any case it is certain that such methods of disposal will prove less and less satisfactory from year to year as the volume of sewage and the concentration of shore population increase. The presence of shellfish beds in locations affected by the discharge of sewage into tide water is a special problem of a serious nature in some localities. It has been exhaustively treated by Fuller (1905 b). The royal sewage commission, in an extensive report on the shellfish question in 1904 (R. S. C., 1904 c), concluded that this evil is a grave one, but that it must be met less by restricting sewage disposal than by regulating the taking and storing of shellfish.

The discharge of sewage into inland waters is less likely to be successful than disposal in the sea. The gravest dangers with large lakes and rivers have arisen from their simultaneous use for sewage disposal and water supply, as in the case of Chicago before the opening of the drainage canal, and to some extent since. In such a case the water supply should always be subjected to its own process of purification; yet where water for drinking is to be taken below the sewage outlet some treatment of the sewage before it discharges furnishes an additional safeguard that is eminently desirable. With smaller bodies of water the increasing proportions of sewage sooner or later exceed the purifying capacity of the stream or pond, and once this point is passed conditions rapidly become intolerable. Just such a condition existed in the Thames, England, prior to the treatment of the sewage of London by chemical precipitation in 1890. In a night trip down the river during one of the investigations of the metropolitan sewage commission of 1882 three of the five members of the commission and their clerk were nauseated by the odor. Gross nuisances of this sort have been created in many streams, both in this country and in England. Blackstone and Neponset rivers, in Massachusetts; Naugatuck River, in Connecticut, below Waterbury; Passaic River between Paterson and Newark, in New Jersey, and Chicago River before the opening of the drainage canal are notorious examples.

By the examination of various rivers it has been possible to fix fairly well the practical limits within which a stream can purify sewage with success. Stearns (1890) estimated that a stream flow of 7 second-feet could safely carry the sewage of 1,000 persons, while if the flow were reduced to 2.5 second-feet a nuisance would result. Hering (1888) set the lower limit at 2.5 to 3.3 second-feet. Goodnough (1903), after a careful study of various Massachusetts streams in connection with the proposed Charles River dam, placed the certain danger line at 3.5 second-feet per 1,000 persons and found that with 6 second-feet trouble rarely follows. Johnson (1905) converted these figures into dilution volumes as follows:

TABLE IV.—*Proportions of sewage which can be discharged into a stream with safety (Johnson, 1905).*

Authority.	Nuisance probable.	Nuisance improbable.
Hering	1 in 16	1 in 45
Goodnough	1 in 23	1 in 36

Roughly, then, it may be said that a stream will purify one-fiftieth of its volume of sewage, but not much more. In summer, when the volume of diluting flow is least, the high temperature accelerates bacterial action and makes an abundant supply of oxygen specially necessary. Table V shows for Merrimac River, above Lawrence, the monthly ratios of stream flow to the sewage-contributing population, estimated at 185,000, together with the mean monthly temperatures and the dissolved oxygen in the river water. The data are graphically shown in fig. 3 and bring out clearly the much greater demand on the purifying power of the river during the summer months. The curve for November and December, 1899, is worthy of special notice, since with no increase in dilution a fall in temperature, with its consequent slackening of fermentation processes, shows a marked rise in dissolved oxygen. Although at the lowest points the dilution does not fall below Goodnough's minimum of 6 second-feet and although the dissolved oxygen averages do not show complete exhaustion, the river

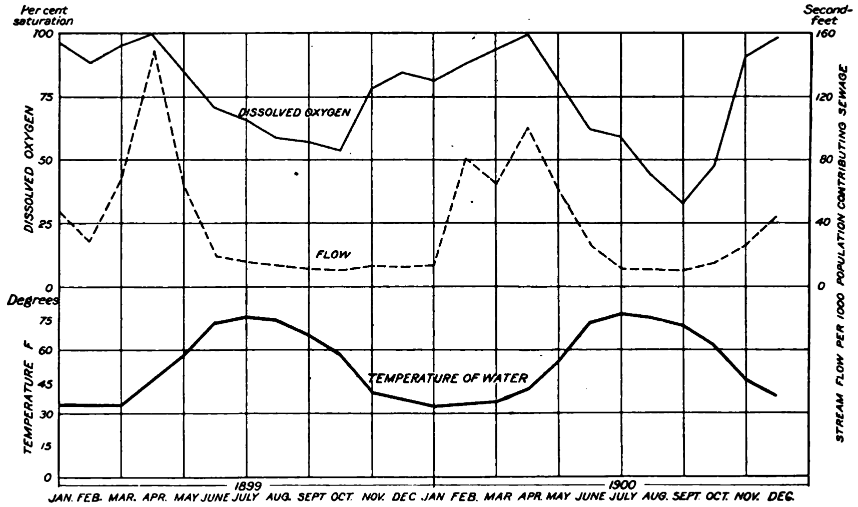

FIG. 3.—Seasonal variations in the condition of Merrimac River at Lawrence, Mass.

is sometimes distinctly offensive during the summer. Theoretically, while any dissolved oxygen remains there should not be putrefaction; practically, any value below 50 per cent of saturation is likely to be accompanied at times by malodorous conditions.

The data in the following table are taken from annual reports of the Massachusetts State board of health (Massachusetts, 1900 and 1901) and from Water-Supply and Irrigation Papers Nos. 35 and 47 of the United States Geological Survey (1900 and 1901):

TABLE V.—*Seasonal conditions in Merrimac River at Lawrence, Mass.*

Month.	1899.			1900.		
	Flow per 1,000 persons discharging sewage (second-feet).	Temperature (° F.).	Dissolved oxygen (per cent of saturation).	Flow per 1,000 persons discharging sewage (second-feet).	Temperature (° F.).	Dissolved oxygen (per cent of saturation).
January	42.6	34	96.3	18.2	33	81.6
February	26.4	34	88.1	89.1	34	87.8
March	64.5	34	95.6	87.7	35	....
April	143.2	....	99.3	100	41	99.1
May	51.6	58	84.4	54.1	54	....
June	16.1	73	71.1	21.4	73	62.1
July	13.4	76	66.6	9.8	77	59.4
August	11.3	74	58.3	10.1	75	43.6
September	10.8	67	57.2	8.2	71	32.5
October	9.7	58	53.7	13.6	62	47.6
November	15.1	40	78.1	31.6	46	91.2
December	15.1	36	84.3	36.6	38	98
Average	34.5	53	77.8	39.9	53	70.3

It is evident that for inland cities, except those situated on the largest lakes and rivers, some other process of sewage disposal must be substituted for the direct discharge into water. In England this is an old story. The first of the royal commissions on sewage disposal investigated the subject in 1857 and reported in 1865 that the only way to prevent the pollution of rivers was to purify town sewage by disposal on land. A second royal commission on rivers pollution, appointed in 1865, made five exhaustive reports between that date and 1874, and a third commission, on the metropolitan district, reported in 1884 that treatment of London sewage was essential to the protection of the Thames. In the United States the Massachusetts legislature in 1872 directed the State board of health to investigate and report on "the disposition of the sewage of towns and cities," eliciting a memorable series of reports from William Ripley Nichols and his associates, and in 1886 the Lawrence experiment station was founded for the study of sewage-disposal problems. To-day 23 cities in the State of Massachusetts alone maintain purification works. According to Fuller (1905), about 28,000,000 persons in the United States are connected with sewerage systems. The sewage from 20,400,000 is discharged into fresh water and from 6,500,000 into the sea, leaving 1,100,000 connected with sewage-purification works.

DISPOSAL OF SEWAGES BY BROAD IRRIGATION OR SEWAGE FARMING.

The most obvious alternative to the discharge of sewage into water is its distribution over the surface of suitable land, allowing the liquid to pass through to join the great reservoirs of ground water below. When the amount of sewage on a given area is not excessive the organic solids do not accumulate, but are gradually decomposed with the formation of soluble products beneficial to the growth of the higher plants. The disposal of waste water in every dooryard early gave an illustration of this process, and the absorption of manure in the fertilization of land indicated the great power of the purifying agents involved.

The practice of sewage disposal by broad irrigation gained a firm empirical basis long before there was any comprehension of the true principles involved. At Bunzlau, Prussia, for example, in the sixteenth century, the water from a famous spring was delivered to the inhabitants and a primitive sewer installed. The sewage from the outfall was distributed for irrigation on privately owned farms as early as 1559 with marked success (Du Marès, 1883). At the Craigentinny meadows part of the sewage of Edinburgh has been treated by irrigation for over two hundred years. The development of this method in England was largely due to the health of towns commission of 1844 and the sewage of towns commission of 1857. The latter commission in 1858 gave a full description of the system at Milan, where the liquid refuse of the city was conducted by a canal called the "Vettabbia" to an irrigation area of about 4,000 acres. The same commission concluded in 1865 that "the right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided."

With the desire to dispose of polluting material grew up a still greater interest in sewage farming as a profitable method of turning organic wastes into valuable crops, Liebig and his followers having laid great stress on the danger of an exhaustion in the nitrogen supply. The two conceptions are well combined in the definition of irrigation by the British metropolitan sewage commission of 1884 as "the distribution of sewage over a large surface of ordinary agricultural land, having in view a maximum growth of vegetation (consistent with due purification) for the amount of sewage applied."

Progress along these lines was rapid in England during the sixties, and many of the present sewage farms were then laid out, as Croydon (1861) and Aldershot (1864). On the continent of Europe the first irrigation plant to be successfully operated on a large scale was at Danzig. In 1869 a contract was signed with an English engineer, Alexander Aird, by which the sewage of the city and 1,300 acres of land were ceded to him for a term of thirty-two years, the entire maintenance of the sewerage system being in his charge. The operation of this plant had a special interest on account of the severe winter weather to which it was subjected. At about the same time the application of sewage to land was begun at Paris by Mille and Durand-Claye, after much preliminary investigation by Schloesing, Muntz, and others, of the chemical and biological principles involved. At present a total area of 13,338 acres at Gennevilliers, Acheres, and two other adjacent places is irrigated with Paris sewage. The flow amounts to 185 million gallons a day, and the standard rate of filtration is 0.012 million (12,000) gallons per acre per day.[a] The sewage, after passage through screen chambers and detritus tanks, is distributed on farms which are mostly owned by private individuals, although the city operates a small area. Part of the land is used for pasturage and part for raising peas, artichokes, tomatoes, and other table vegetables. The sewage farms of Berlin do not date quite so far back. Operations were first begun at Osdorf in 1876, after a long investigation under the leadership of Rudolf Virchow. An area at Falkenberg was added in 1879, and two areas at Grossbeeren and Malchow were added in 1882. The farms are to-day the largest in the world, the sewage of a population of 1,750,000 being treated on 22,881 acres of land at a rate of 0.003 million gallons per acre per day. The crops are chiefly timothy and Italian rye grass. The farms are operated mainly by convict labor under German military discipline (Roechling, 1892).

The English sewage farms are so designed that the sewage is allowed to run continuously over the surface of the soil in as thin a film as possible without being specially encouraged to pass downward. As a rule, the sewage is brought to the highest level on the farm and thence distributed by open carriers following the contours; these in turn discharge through lateral carriers or ditches. On many farms special areas of porous soil are leveled so that they may be completely flooded, serving for intermittent filtration, which is discussed on pages 35–42.

To obtain an available area of proper soil is the chief problem in sewage farming. A light soil on a sandy or gravelly subsoil proves most satisfactory, while peat, chalk, and clay are bad. All three are too impervious, and the last two are likely to discharge unpurified sewage through cracks and fissures. With unsuitable soils rates of filtration must be low. Rideal (1901) estimates that the sewage from 100 persons can be treated on an acre of loamy gravel and that the number may rise to 500 under rarely favorable circumstances, while with stiff clay it falls to 25. The rates commonly in use in England vary from 0.002 million gallons per acre per day at Leamington and

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[a] Throughout this report rates of filtration are expressed in millions of United States gallons per acre per day, and where possible in "net rates," i. e., total quantity passed in a given period divided by the number of days in that period.

Wrexham to 0.015 at Cheltenham and Birmingham (Watson, 1903). German figures range from 0.002 at Brunswick to 0.007 at Danzig, and probably average about 0.004 (Bredtschneider and Thumm, 1904).

When an irrigation farm is overdosed it becomes "sewage sick," to use an expressive English term. The surface clogs, pools are formed, putrefaction begins; only a complete rest restores the health of the area. Under such conditions the temptation to discharge unpurified sewage into the nearest stream is very strong. At times of rain, when sewage flow is highest, the crops are least in need of water and may be seriously damaged by it. The aims of sewage purification are too apt under such conditions to be sacrificed to those of agriculture. Thus, at the famous Craigentinny meadows, where profitable crops are obtained from once barren areas of blown sands, we are told that "the great bulk of the foul water merely runs over the surface of the ground and deposits a portion of its suspended matter" (Barwise, 1904). Many of the English farms, on the other hand, have been operated for thirty years with no nuisance and without the accumulation of offensive sludge.

The statistics for eight of the principal English farms have been compiled from the fourth report of the royal sewage commission (R. S. C., 1904 a, b) to form Table VI, and they give a fair idea of general practice. The low rates on clayey soil at Leicester, Rugby, and South Norwood will be noticed, as well as the fact that careful screening and settling has in most cases been found a necessary preliminary. The analyses, which from their source may be considered representative, indicate that English irrigation effluents are by no means of exceptional quality, although the Nottingham and Cambridge results are excellent. The Aldershot plant appears to be doing fairly well, considering the very strong sewage with which it deals, but at Altrincham and other places the purification is much less satisfactory. By incubator tests the Nottingham and Cambridge effluents stood very high, and of the samples from Leicester and Aldershot 90 per cent gave no secondary putrefaction. Norwood, Croydon, and Rugby, on the other hand, gave putrescible effluents about one-fourth of the time. On the whole, it seems fair to conclude from a general survey of English conditions that when a sufficient area of porous soil with a low water table is available a well-managed irrigation area may prove a satisfactory method of sewage disposal from the sanitary standpoint.

TABLE VI.—*Statistics of sewage farms in England (R. S. C., 1904 a, b).*

Farm.	Date of construction.	Average daily flow (million gallons).	Area of filter beds (acres).	Rate (million gallons per acre per day).	Character of soil and subsoil.	Character of sewage.	Method of treatment.	Analyses (parts per million).							Remarks.
								Material.	Total suspended solids.	Nitrogen as—				Oxygen consumed in 4 hours at 80° F.	
										Total organic.	Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.		
Aldershot camp..	1864	1	120.5	0.008	Sand...........	Purely domestic.	Screening, settling tanks, and land filtration.	Sewage...	366	50.6	78.7	16.2	......	207.9	Average of 3 sets of 24-hour samples, January, 1902.
								Effluent..	.....	9.4	18.5	2.6	32.1	27.2	Average of 17 samples, 1900-1901.
Altrincham (Cheshire).	1870	.8	35	.023	Peaty soil lying upon sand and gravel.	Domestic.....	Settling tank and land filtration.	Sewage...	720	12.4	22.9	6.2	......	52.2	Average of 9 samples, 1900-1901.
								Effluent..	.....	2.6	12.3	1.3	......	17.5	Average of 16 samples, 1900-1901.
Beddington (Croydon).	1861	4	420	.01	Gravelly loam overlying gravel and sand.	Almost purely domestic.	Screening, surface irrigation, and filtration.	Sewage...	345	20.7	45	9.1	......	124.8	Average of 7 sets of 24-hour samples, January, 1902.
								Effluent..	.....	2.61	14.8	1.4	3.7	14.1	Average of 18 samples, 1900-1901.
Cambridge.......	1895	2.25	74	.3	Sandy loam overlying gravel and sand.	Mainly domestic; some brewery refuse.	Screening, settling tank, and land filtration.	Sewage...	265	18.8	38.2	9.1	......	10.8	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	2.1	6.5	.9	12.6	8.1	Average of 18 samples, 1900-1901.
Leicester.........	1891	7.25	1,350	.005	Stiff clayey soil overlying dense clay.	Three-fourths domestic; one-fourth trade refuse.	Screening, settling tanks, surface irrigation and filtration combined.	Sewage...	341	23.4	81.2	11.9	......	223.5	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	4.5	16.5	2	5.1	25	Average of 13 samples, 1900-1901.
Nottingham,....	1880	7	651	.011	Light sandy loam and gravel overlying gravel and sand.	Four-sevenths domestic; three-sevenths trade refuse.	Screening (partial) and land filtration.	Sewage...	519	31.5	39.8	14.5	......	232.1	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	.8	1.3	.3	20.6	1.9	Average of 13 samples, 1900-1901.
Rugby...........	1867	.3	35	.009	Heavy loam overlying stiff clay.	Mainly domestic.	Screening, settling tanks, surface irrigation and filtration combined.	Sewage...	473	32.9	61.1	17.3	......	184.4	Average of 3 sets of 24-hour samples, February, 1902.
								Effluent..	.....	1.7	16.2	1.8	5.2	14.1	Average of 19 analyses, 1900-1901.
South Norwood.	1864	.6	152	.004	Clay soil resting on London clay.	Purely domestic.	Screening, settling tanks, and surface irrigation (with a little filtration).	Sewage..	219	14.9	35.4	6.7	......	77.1	Average of 7 sets of 24-hour samples, January, 1902.
								Effluent..	.....	10.4	8.7	1	3.9	14.4	Average of 11 analyses, 1900-1901.

The economic advantage of sewage farming is somewhat more doubtful. English chemists estimate the manurial value of sewage at from 1 to 4 cents a ton (Rafter and Baker, 1894). This value can no doubt in part be recovered, since the crops grown on sewage fields are often astonishingly heavy. Whether it really pays to recover it depends on local economic conditions. In many English towns the operation of farms has proved unprofitable, and there is some tendency toward their abandonment. Lieut. Col. A. S. Jones and others are, however, ardent advocates of the process; and in certain cases the farm, besides paying all running expenses, yields in some years as much as $12 an acre toward rent (Baker, 1904). McGowan, Houston, and Kershaw, in their valuable report to the royal sewage commission, conclude:

> Although we are of opinion that sewage farms in general can never be expected to show a profit if interest on capital expenditure is included, the fact that in favorable seasons some of them more than cover the working expenses is a point in favor of cropping in connection with the land treatment of sewage. [R. S. C., 1904 c.]

With regard to the question of the sanitary quality of the produce grown on a sewage field, the experience of Berlin and Paris indicates that there need be no serious danger of the spread of disease from irrigated crops. The writers believe, however, that fruits and vegetables to be eaten raw should never be so treated; and McGowan, Houston, and Kershaw (R. S. C., 1904 c) would limit sewage farms to stock raising, saying:

> We are, on the whole, not in favor of sewage farms being utilized for the raising of crops for human consumption.

In the western part of the United States the conditions for sewage farming are specially favorable. In the arid regions some form of irrigation is essential and the manurial value of sewage is reenforced by its water value. The first plant in this country was laid out at Cheyenne, Wyo., in 1883, and to-day there are a score or more of sewage farms in operation, of which those at Los Angeles and Salt Lake City are the largest. The experience of Los Angeles is of considerable interest as indicating the value of sewage in such a region. Prior to 1889 the sewage from the city, amounting to 7 million gallons, was carried to the so-called Vernon district, where it was taken by the South Side Irrigation Company and distributed to adjacent farms. So useful did the sewage prove that the value of the land rose from $2.50 an acre to from $15 to $25. A boom followed, house lots were developed, and the population so increased that the sewage, which had built up the district, became a nuisance and had to be taken elsewhere.

In the East the problem of sewage irrigation takes on a different aspect. The high cost and poor quality of land and the heavy rains of spring and autumn combine to make the success of such a venture more than problematical. It is true that the waste of valuable manurial elements is unfortunate, and authorities like Rafter (1897) have been strongly moved by such considerations. The saving of organic nitrogen, however, appears to-day in a less important light than formerly, since we know that its dissipation may be made good from the ocean of the atmosphere by the activities of the nitrogen-fixing bacteria. At any rate the question is one which must be judged on a basis of dollars and cents. There are valuable elements in sewage, as there is gold in sea water; but if it costs more to save them than they are worth after they are saved we must let them go. On the Pacific coast sewage farming is profitable. In the East, under present conditions, it is unlikely to prove so.

TREATMENT OF SEWAGES BY CHEMICAL PRECIPITATION.

Parallel with the development of broad irrigation there grew up a method, or a group of methods, for the utilization of the useful elements in sewage on a different principle. The idea that sewage sludge may be valuable is so discredited to-day that it is difficult to believe that the first attempts at chemical treatment were made with a view to the recovery of its constituents in a "portable and consequently marketable form." Such, however, was the object with which numerous processes were devised in the early sixties. Between 1856 and 1876 no less than 417 patents were issued in England for processes connected with the chemical precipitation of sewage.

The various methods of treatment consist, as a rule, of two stages—the addition of some substance which will produce a flocculent precipitate, and the sedimentation of the mixture to separate the heavy sludge from the supernatant liquid. The precipitants used are various, but the active elements in most cases are salts of lime, aluminum, or iron. The rivers pollution commission in its report of 1870 discussed the action of lime, lime and chloride of iron, sulphate of aluminum, Sillar's "ABC" mixture (alum, blood, and clay with other substances), and Holden's compound (iron sulphate, lime, and coal dust). Hazen (1890) in 1889 carried out for the Massachusetts State board of health an elaborate series of experiments, from which it appeared that either ferric salts or a mixture of ferrous sulphate with lime proved most satisfactory. In the first case ferric hydroxide was precipitated, and in the second case ferrous hydroxide, calcium carbonate, and various insoluble organic lime salts. Ferrous sulphate alone gave less satisfactory results, as did also sulphate of aluminum.

Exhaustive studies of various precipitants were made by Dibdin in connection with the treatment of the sewage of London, results and cost of different processes being worked out in great detail. All suspended matter could be removed, and with regard to the dissolved organic matter the efficiency ranged from a removal of 10 per cent with 52 parts per million of lime to a removal of 31 per cent with 784 parts of lime, 168 parts of ferrous sulphate, and 560 parts of sulphate of aluminum, and a removal of 52 per cent with 9,800 parts of lime, 1,400 parts of ferrous sulphate, and 700 parts of sulphate of aluminum. The annual cost for a daily flow of 157 million gallons was estimated at $60,000 for the first result quoted, $400,000 for the second, and nearly $50,000,000 for the third. In general it was found that lime was the best basis, and for use in combination with it iron salts were preferable to those of aluminum. The combination finally determined on was 56 parts of calcium oxide (4 grains per gallon) with 14 parts of ferrous sulphate (1 grain per gallon). After the addition of precipitants the sewage is allowed to settle in tanks where it either remains quiescent for a time or flows through slowly and continuously. The second or continuous method is most satisfactory, and a capacity of from one-half to twice the daily flow is sufficient for sedimentation. For a complete separation on a small area a tank of special form is sometimes used, whose bottom is an inverted cone in which the sewage passes upward, its flow supplementing the action of gravity. At a certain level in the tank the precipitated material collects, so as to form a sort of filtering layer through which the ascending sewage must pass. A tank of this form (Röckner-Rothe type) was installed at the World's Columbian Exposition in Chicago in 1893 (Hazen, 1894); it was practically identical with the Dortmund tank extensively used in German plants for the treatment of industrial wastes.

The results to be expected from the chemical treatment of sewage may be learned from the experience of London. The sewage of the city was originally discharged from the various sewers directly into the Thames, producing a nuisance which culminated in the historic stink of 1858. To cope with these conditions a system of intercepting sewers was completed in 1865 which discharged the sewage from the district north of the river at Barking Creek and that from the south side at Crossness, about 12 miles below London Bridge. This arrangement proved satisfactory for a time, until the volume of sewage had too greatly increased. By 1875, however, it became necessary to discharge part of the flow on the flood tide; the liquid carried up the river and the solids deposited on the shores became once more a serious nuisance. In 1882 the metropolitan sewage commission was appointed and advised the removal of solid matter from the sewage by deposition or precipitation. In accordance with its recommendations precipitation works were constructed at both outfalls, the sewage being treated, as noted above, with 56 parts per million of calcium oxide and 14 parts per million of ferrous sulphate. At the present time the same system is still in force. The sewage from the city of 4,500,000 inhabitants amounts to 280 million gallons per day, and 7,200 long tons of sludge are daily carried 50 miles out to sea by a fleet of six dumping boats. The total cost of treatment is nearly $900,000 a year (Baker, 1904). The results of the chemical treatment for London are indicated in Table VII and show a removal of somewhat over three-fourths of the suspended matter, but only slight improvement in the soluble constituents. The effluent is by no means purified. It is merely so improved by the removal of most of its solids that its discharge into the Thames is for the time being permissible.

TABLE VII.—*Results of chemical precipitation at London, 1894 (Dibdin, 1903).*

[Parts per million.]

Source.	Material.	Suspended solids.	Dissolved material.			
			Total.	Oxygen consumed in 4 hours at 80° F.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.
Northern outfall	Sewage	417	862	44.5	35.6	4.1
	Effluent	99	910	46.2	36.9	4.2
Southern outfall	Sewage	441	1,300	53.1	34.8	4.9
	Effluent	87	1,420	44.5	28.9	3.9

At Manchester conditions appeared somewhat more favorable for precipitation on account of the presence of certain chemicals in the factory wastes, and only 31 parts of calcium oxide and 17 parts of ferrous sulphate were added. The results with respect to the total organic constituents are indicated in Table VIII. The figures are five-year averages of the results of analyses made twice a day on hourly samples. The purification of the effluent proved inadequate to meet local conditions, and the system has been abandoned in favor of newer biological processes.

TABLE VIII.—*Results of chemical precipitation at Manchester, England, 1900–1904 (Manchester, 1900–1904).*

[Parts per million.]

Material.	Oxygen consumed in 4 hours.	Oxygen consumed in 3 minutes.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.
Sewage	116	56.7	23.6	5.9
Tank effluent	76.4	37.2	24.2	3.9

At Birmingham a number of chemical processes were tested in 1871 and found unsatisfactory. Watson, the present engineer of the drainage board, comments:

> I venture to say that a similar conclusion would have been arrived at if the committee, instead of trying only seven chemical processes, had tried all the 454 processes which were patented previous to 1886. [Watson, 1903.]

At Salford a thorough test of 13 different precipitants yielded no satisfactory effluents.

The disposal of the sludge is a serious problem in chemical precipitation. Its quantity is considerable, amounting to 26 tons per million gallons of sewage at Salford, 21 tons per million gallons at Manchester, and 60 tons per million gallons at Chorley. Of this crude sludge 90 to 95 per cent is water. Wallace found the composition of the air-dried residue from eight different English plants to average 12 per cent of water, 26 per cent of organic matter, 1 per cent each of nitrogen and phosphoric acid, and 35 per cent of sand (Robinson, 1896). Far from being marketable, as the projectors of the process dreamed, the disposal of this sludge generally involves considerable expense. In 1894 a canvass by the local government board showed that of 234 places using chemical processes only 30 were able to obtain any revenue from sludge. In some German plants the sludge is evaporated and burned for generating gas. The usual course, however, is to compact it in filter presses and dispose of the press cake by burning it or burying it in the ground.

On the whole, chemical precipitation has become somewhat discredited of recent years. The cost of chemicals is considerable, the disposal of the sludge is vexatious, and the effluent produced is imperfectly purified and always subject to secondary putrefaction. Except under special conditions this treatment can be considered only a preliminary process, to be followed by some final biological treatment which shall effect real purification. Even in this rôle the process is generally less applicable than the septic tank, since, as compared with the latter, it produces results only slightly better with a considerable additional cost for chemicals and with an increase in the quantity of sludge.

In special cases, however, chemical treatment still has its application. While most English cities are abandoning chemical precipitation for some newer process, Glasgow is installing new tanks which will eventually handle 140 million gallons of sewage daily, using lime and sulphate of alumina as precipitants. The experience of Worcester, Mass., is of considerable interest in this connection, since there, too, chemical precipitation is apparently likely to be maintained. In 1867 the city of Worcester was permitted to use as a common sewer Mill Brook, which discharges into Blackstone River. In 1880 vigorous complaints began from Millbury and other towns below that the stream was so foul as to be a nuisance and a danger to the health of the community. Phineas Ball, Colonel Waring, and others reported various plans for relief, and in 1882 the State board of health recommended the installation of intermittent filters. In 1886 the legislature ordered that the city should remove from its sewage before discharge into Blackstone River "the offensive and polluting properties and substances therein, so that after its discharge into said river it shall not create a nuisance which might endanger the public health." A chemical precipitation plant was duly installed in 1890, but the condition of the river remained bad. In 1895 Millbury brought suit against Worcester on the ground that the act of 1886 had not been complied with. After full expert discussion it appeared that the condition of the river was in part due to the past pollution which had for years accumulated in its bed as sewage mud, and in part to the imperfectly purified chemical effluent still being discharged. The courts declared that the city had acted in good faith in attempting to carry out the act of 1886, but ordered that it should take further steps to comply with its provisions. Since that date sand areas for intermittent filtration have been progressively added for the final purification of the chemical effluent. It is possible in this case that chemical treatment is the best available preliminary process, since the city sewage contains free sulphuric acid and sulphate of iron from the wire works which aid the chemical process and perhaps interfere with bacterial action.

In 1904, 4,622 million gallons of sewage were received at the Worcester works, of which 4,227 million gallons were treated chemically. Six hundred million gallons of the chemical effluent and 395 million gallons of raw sewage were treated on sand filters. Lime is the only precipitant used, in the amount of 120 parts per million, sufficient iron being already present in the sewage to complete the reaction. For every million gallons of sewage treated 5,756 gallons of wet sludge are obtained, containing 6.93 per cent of solids. After pressing, this is reduced to 5.7 tons of pressed sludge containing 28.9 per cent of solids. The cost of pressing and sludge disposal amounts to over $5 per million gallons. The analyses of sewage and effluent from 1894 to 1904 show that the yearly removal of the total albuminoid ammonia has varied from 46 to 63, averaging 52 per cent; of total oxygen consumed from 37 to 59, averaging 51 per cent; of suspended albuminoid ammonia from 83 to 98, averaging 93 per cent; and of suspended oxygen consumed from 77 to 89, averaging 82 per cent (Worcester, 1905). The results for 1904 are shown in Table IX.

TABLE IX.—*Results of chemical precipitation at Worcester, Mass., 1904 (Worcester, 1905).*

[Parts per million.]

Material.	Nitrogen as—			Oxygen consumed in 2 minutes' boiling.	
	Free ammonia.	Albuminoid ammonia.			
		Total.	Soluble.	Total.	Soluble.
Raw sewage	15.9	6.8	2.5	96.9	59.7
Chemical effluent	14.4	3.4	3.1	54.2	43.1

Another large American precipitation plant is that at Providence, R. I., where since the sewage effluent is discharged into a tidal estuary the removal of suspended solids alone is all that is necessary. Precipitation was recommended by S. M. Gray after an exhaustive investigation in 1884, but the plant was not finally installed until 1902. Comparative statistics for the operation of the Worcester and Providence purification works in 1903, copied from Fuller, are given in Table X.

TABLE X.—*Statistics of chemical precipitation at Worcester, Mass., and Providence, R. I., 1903 (Fuller, 1905 a).*

	Worcester.	Providence.[a]
Population connected to sewers, estimated	122,000	170,000
Average daily sewage flow, total ... million gallons	15.55	20.38
Average daily sewage flow, treated ... do	14.39	20
Total annual sewage flow treated ... do	5,250	7,300
Applied lime ... pounds per million gallons	871	606
grains per gallon	6.1	4.2
Applied copperas ... pounds per million gallons	0	65
grains per gallon	0	.46
Gross capacity of basins ... million gallons	5.5	11.1
Percentage of removal:		
Total organic matter by albuminoid ammonia	51.69	[a] 49.80
Suspended organic matter by albuminoid ammonia	91.58	[a] 82.54
Wet sludge:		
Average pressed daily ... gallons	67,200	95,600
Percentage of total sewage flow	.4671	.4776
Average percentage of dry solid contents	7.44	5.37
Average amount of lime added per 1,000 gallons ... pounds	33.5	23.6
Pressed sludge cake ... tons daily	69	76
percentage of dry solids	30.3	28.25
Dry solids in sludge:		
Tons daily	20.80	21.40
Tons per million gallons	1.45	1.07
Tons per 1,000 population per annum	62	46
Cost of sludge pressing and disposal:		
Per ton of dry solids	$3.39	$2.27
Per million gallons sewage flow	$4.91	$2.44
Cost of chemical precipitation (labor and supplies) per million gallons	$4.01	$3.31
Total cost of operation:		
Per million gallons	$8.92	$5.75
Per capita connected to sewers per annum	$0.384	$0.248
Cost per ton:		
Lime	$6.00	$6.90
Copperas		$7.80
Minimum wage per hour for laborers	$0.23½	$0.15

[a] Providence sewage well screened before treatment.

Before leaving the subject of chemical treatment it will be well to refer briefly to certain special processes which have been suggested and adopted in exceptional cases without finding general application. For example, with the Liernur system of sewerage in use in certain Dutch and Belgian cities, which lie at too low a level for gravity systems, the excreta diluted with a small volume of water are drawn off by suction through a system of tight sewers, and sewage of this type has been handled by direct evaporation, the residue being used as fertilizer. Its application is naturally limited (U. S. Dept. State, 1895). The Degener process applied in some German cities involves mixture of the sewage with crushed lignite, precipitation with ferric sulphate, pressing of the sludge, and treatment of the effluent with bleaching powder. The process is costly, but at Potsdam and Tegel is said to produce a very perfect effluent (Grünbaum, 1902). The bleaching powder in this process is supposed to disinfect the final effluent; and the same end is aimed at in a number of chemical processes based on the use of such substances as ozone and the oxychlorides. The Webster process allowed sewage to flow between iron electrodes so that the chlorides present were electrolyzed, liberating free chlorine and oxygen and forming iron salts. In the Hermite process a stronger action was obtained by electrolyzing sea water and adding it to the sewage (Rideal,1901). Considerable interest has been manifested in these and similar methods during the last year. Disinfection processes, however, ignore the fundamental problem of sewage disposal, which is the production of an oxidized, not of a sterile, effluent. Until a really purified and stable effluent has been produced disinfection is a step in the wrong direction.

An interesting method has been suggested by Adeney and installed by Kaye Parry at Dundrum, Chapel-Izod, and other Irish towns. It aims at the addition of chemicals in such a way as to favor rather than to check biological action. The sewage is first precipitated by oxanite, which is a crude sulphate of manganese mixed with the higher oxides of that element, and then nitrate of soda is added to the supernatant liquid. The manganese supplies the sludge with oxygen, so that a rapid aerobic fermentation occurs and the nitrate performs the same function for the effluent.

PURIFICATION OF SEWAGES BY INTERMITTENT FILTRATION THROUGH SAND.

The only general method for the purification of sewage is its oxidation by micro-organisms. We have seen how this process has been empirically utilized in dilution and in broad irrigation. Its scientific principles were grasped by a few investigators at an early date. About 1865 Alexander Mueller described the purification of sewage as a process of digestion and mineralization carried out by minute animal and vegetable organisms (Rideal, 1901). In 1878he took out a patent for a "process for the disinfection, purification, and utilization of sewage by the scientific cultivation of yeastlike organisms" (Bruch, 1899). In 1877 the fact that the purification of sewage is due to bacteria was demonstrated by Schloesing and Muntz in a series of experiments in which it was shown that nitrification did not occur in soils sterilized by heat or chloroform (Schloesing and Muntz, 1877). Warington reported further suggestive results along this line in 1892.

These suggestions appear to have made little impression in Great Britain and the United States. Meanwhile, however, the practical side of the subject was undergoing an important development in England. In 1870 Sir Edward Frankland carried out a series of significant experiments, the results of which were published in the first report of the rivers pollution commission. Sewage was filtered both upward and downward through various soils at different rates, and it was shown that a good effluent could be obtained by downward filtration through coarse gravel at a rate of 0.08 million gallons per acre per day, while upward filtration produced only a foul and turbid effluent. Doubling the rate interfered with the purification, and it was seen that a resting or aerating period between the applications of sewage was a necessity. The principle of the process as a chemical oxidation of organic matter to water, carbon dioxide, and nitrates was clearly recognized, as well as the practical necessity for intermittency in operation. The cycles in the life of a sewage filter were compared to the inspirations and expirations of the lungs (rivers pollution commission, 1870).

These researches indicated that with suitable soil the process of broad irrigation might be made more intensive, the growing of crops being subordinated to the treatment of sewage at a more rapid rate. This principle was quickly applied on a practical scale by J. Bailey-Denton, who constructed an intermittent filter at Merthyr Tydvil, Wales, in 1871. Beds 20 acres in area were furrowed, cropped, and operated at a rate of 0.06 million gallons per acre per day. This rate was later reduced to 0.016 by the addition of more irrigation land, but the original plant worked admirably and was of importance as a practical demonstration of Frankland's experiments on a large scale (Bailey-Denton, 1882). Neither Frankland nor Bailey-Denton, however, understood the biological nature of the process. The latter said of his filters in 1882:

> The assimilative powers of growing plants are brought to bear on the fertilizing elements of the sewage at the same time that the percolation of the sewage through the soil brings it in contact with the atmospheric air pervading the soil and renders it harmless by oxidation, as explained by the rivers pollution commissioners.

Altogether, it is clear that in the early eighties the *theory* of sewage oxidation was understood by French and German investigators. On the other hand, the *practice* of intermittent filtration had been empirically worked out in England by Frankland and Bailey-Denton. The laboratory investigations, however, were academic and the practical data incomplete. To combine a sound conception of the biological principles involved with a study of the engineering data of operation on a practical scale was left for American investigators. English sanitarians have not been slow to recognize that "it was primarily due to the Massachusetts State board of health, who began their investigations in November, 1887, and have continued them ever since, that the bacterial treatment of sewage has been forced on public attention" (Watson, 1903). For the mass of data accumulated and the thoroughness with which these data were analyzed, as well as for the almost revolutionary effect which they worked in sewage practice, the Massachusetts experiments well deserve the term of "classic," by which they are so commonly designated.

In 1886 the legislature of Massachusetts charged the State board of health with the advice of cities and towns, corporations, and individuals as to water supply and sewage disposal and ordered it to collect information and conduct experiments on the purification of sewage. Hiram F. Mills, a distinguished hydraulic engineer and a member of the board, organized the investigation, with the assistance of T. M. Drown and W. T. Sedgwick, both of the Massachusetts Institute of Technology, as chemist and biologist, respectively. An experiment station was fitted up in 1887 on the bank of Merrimac River at Lawrence, under the immediate charge of Allen Hazen. Here ten circular cypress tanks 17 feet in diameter and 6 feet deep were filled with various filtering materials—sand, gravel, peat, river silt, loam, garden soil, and clay—and dosed with sewage pumped from the city sewer. The results exceeded the hopes of the investigators. By passage through a fairly porous soil on the intermittent plan, one dose being applied every twenty-four hours, sewage could be converted into a clear and completely nitrified effluent. Peat and garden soil proved too impervious and, although operated at very slow rates, clogged. In this condition the air supply was cut off and nitrification failed. All the other filters showed good purification at rates of from 0.02 to 0.1, the quality of the effluents being equal in many cases to that of well waters in use in the city of Lawrence.

The true nature of sewage purification as a bacterial oxidation was clearly brought out in these experiments. Intermittency of application supplies the needed oxygen, and any fairly porous material will serve as a resting place for the active bacteria.

> The experiments with gravelstones give us the best illustration of the essential character of intermittent filtration of sewage. In these, without straining the sewage sufficiently to remove even the coarser suspended particles, the slow movement of the liquid in thin films over the surface of the stones, with air in contact, caused to be removed for some months 97 per cent of the organic nitrogenous matter, a large part of which was in solution, as well as 99 per cent of the bacteria, which were of course in suspension, and enabled these organic matters to be oxidized or burned, so that there remained in the effluent but 3 per cent of the decomposable organic matter of the sewage, the remainder being converted into harmless mineral matter.
>
> The mechanical separation of any part of the sewage by straining through sand is but an incident, which, under some conditions, favorably modifies the result; but the essential conditions are very slow motion of very thin films of liquid over the surface of particles having spaces between them sufficient to allow air to be continually in contact with the films of liquid.
>
> With these conditions it is essential that certain bacteria should be present to aid in the process of nitrification. These, we have found, come in the sewage at all times of the year, and the conditions just mentioned appear to be most favorable for their efficient action and at the same time most destructive to them and to all kinds of bacteria that are in sewage. [Mills, 1890.]

The organisms active in the nitrifying process, isolated independently by Winogradsky in France and by Richards and Jordan (1890) at Lawrence, have been studied by a number of bacteriologists, of whom Schultz-Schultzenstein (1903) and Boullanger and Massol (1903) are perhaps the latest. The necessity for an alkaline base for nitrification, known to agriculturists since the time of Varro, has been confirmed by these observers, who find that free acids, organic or inorganic (0.5 per cent), and nitrates or nitrites in 1 to 3 per cent solution, quickly check the work of the organisms. A marked excess of free ammonia or of any alkali has the same effect. Thus Warington found that a 12 per cent solution of urine having a maximum alkalinity of 446 parts of ammonia as carbonate would stop nitrification. At Burton sewage containing 100 parts of free lime would not nitrify till it was neutralized (Barwise, 1904). Rideal also notes a harmful effect due to carbon dioxide, and Letts believes that sodium chloride from sea water hinders the formation of nitrates at Belfast (R. S. C., 1902 a). The optimum temperature for the reaction lies between 28° and 37° C. It is stopped in the neighborhood of 50° C.

Later work at Lawrence, where numerous small experimental filters have been operated since 1890, has brought out further details of the process of intermittent filtration. In the 1891 report, prepared by Allen Hazen, the chemist in charge of the station, it was shown that while most of the organic matter of the sewage is actually destroyed and while there is no important storage in the depths of the filter, its surface accumulates a certain amount of stable organic matter which must be removed at intervals. It was made apparent that in severe winter weather the quality of the effluent, while considerably deteriorated, was still reasonably satisfactory. The maximum rate at which sewage could be conveniently applied varied from 0.03 with sand of an effective size of 0.03 mm. to 0.06 with sands of 0.06 to 0.35 mm., 0.1 with sands of 0.17 and 0.48 mm., and 0.2 with gravel of 5 mm.

One of the strong points about the Lawrence experiments has been their continuity for a sufficient period to show the long life of intermittent filters, four of the original outdoor filters having been operated for seventeen years. A comparison of the effluents during the first seven and the last nine years of operation has been compiled from the reports of the State board and is shown in Table XI. Although, with a considerably increased concentration of sewage the effluents have deteriorated, yet the percentage purification has only slightly decreased, and the effluents are still of good quality.

TABLE XI.—*Results of intermittent filtration at Lawrence, Mass., in successive periods (Massachusetts, 1895–1903).*

	Quantity of sewage applied (gallons per acre per day).	Temperature (°F.)	Analyses (parts per million).					
			Nitrogen as—				Oxygen consumed in 2 minutes' boiling.	Chlorine.
			Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.		
1888–1894								
Filter No. 1	76,000	53	2.3	0.4	16.8	0.18	4.7	68.5
Filter No. 2	34,000	52	1.7	.1	15.9	.15	1.7	65.4
Filter No. 4	27,000	52	1.7	.2	10.4	.02	3.7	59.9
Filter No. 6	47,000	53	1.9	.3	16.4	.34	3.2	68.1
Filter No. 9A	74,000	53	4.9	.3	18.3	.08	3.2	80.2
Sewage			18.8	5.5			36.2	68.4
1895–1903.								
Filter No. 1	51,000	55	8.6	.6	25.8	.23	6.6	94
Filter No. 2	30,000	54	5.8	.3	28	.10	3.3	91.4
Filter No. 4	16,000	54	2.4	.2	26.9	.03	1.8	86.1
Filter No. 6	51,000	54	7.6	.6	26	.31	5.8	90.8
Filter No. 9A	52,000	54	8.8	.5	26.7	.09	5.6	89.6
Sewage			32.6	5.9			41.3	91.8

The early Massachusetts experiments led at once to practical developments. In the 1887 and 1888 reports of the board of health preliminary results were announced, and in 1889 the board reported that a plan suggested for the disposal of the sewage of the Mystic Valley on the Saugus marshes was impracticable on account of the peaty nature of the soil. Also in 1889, in accordance with the favorable results obtained at Lawrence by filtration through coarse sand, the first large intermittent filtration area in the State was laid out in the town of Framingham. Gardner and Marlboro followed in 1891, and at the same time the first filter in Connecticut was built at Meriden.

In 1903 (Massachusetts, 1904) the State board of health of Massachusetts discussed the results of the operation of 23 plants in the Commonwealth. All made use of intermittent filtration, and the report concludes that—

> The ready availability of sand and gravel areas naturally adapted for the purification of sewage, the simplicity of the process, and the small cost of maintenance have made this method of purification the most advantageous for adoption in practically all the cases in which sewage-purification works have been found necessary, and the resulting effluents turned into the stream have been satisfactory in all cases where the works are of sufficient capacity and have received proper care.

The principal analytical data from the report are shown in Table XII, which gives a fair idea of the operation of the intermittent process. It will be noted that the rates vary in general from 0.05 to 0.1 and that the effluents are in most cases of satisfactory quality. They are superior in almost every instance to those obtained at the English sewage farms, as shown in Table VIII.

TABLE XII.—*Statistics of intermittent filtration in Massachusetts (Massachusetts, 1904; Worcester, 1905).*

Place.	Date of construction.	Average daily flow (million gallons).	Area of filter beds (acres).	Rate (million gallons per acre per day).	Population contributing sewage.	Preliminary treatment.	Material.	Average of monthly analyses, 1903[a] (parts per million).				
								Nitrogen as—				Oxygen consumed in 2 minutes' boiling.
								Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.	
Andover	1898	0.125	3.65	0.0342	3,600	Screening; sedimentation	Sewage	39.7	5.6			49
							Effluent	9.1	.5	8.3	0.2	7.4
Brockton	1894	.878	21.48	.0409	25,000	Partial sedimentation	Sewage	43.8	12.9			219
							Effluent	1.9	.1	30.8	.1	3.3
Clinton	1899	.785	23.5	.0334	10,000	.....do	Sewage	33.2	7.9			113.7
							Effluent	.8	.6	4.4	.2	11.2
Concord	1898	.312	3.3	.0945	1,200	Screening	Sewage	5.7	1.4			13.6
							Effluent	.01	.09	8.5	0	1.1
Framingham	1889	.652	19.9	.0328	7,500	.....do	Sewage	26.1	6.5			47.3
							Effluent	1.8	.2	9.9	.2	2.6
Gardner (Gardner system).	1891	.302	2.5	.1208	3,500	Sedimentation	Sewage	20.2	4.9			49.2
							Effluent	14.8	.7	.4	0	10.7
Hopedale	1892	.150	2.3	.0652	2,000	Septic tank	Sewage	18.3	2.8			29.8
							Effluent	8.6	.7	15.9	.3	7.2
Leicester	1894	.030	.36	.0833	500	Sedimentation	Sewage	22	4.1			50.8
							Effluent	5.8	.7	9.1	.4	9.6
Marlboro	1890	1.100	11.2	.0982	10,000	.....do	Sewage	25.9	4.4			44.4
							Effluent	10.2	.5	3.5	.3	7.3
Natick	1895	.566	11.1	.0510	4,000	Screening	Sewage	12.2	2.6			32.7
							Effluent	5.1	.3	2.2	.2	4.4
Pittsfield	1890	1.456	21.67	.0672	15,000	.....do	Sewage	12	8.2			79.2
							Effluent	2.2	.3	6.7	.2	3.8
Southbridge	1899	.350	7.25	.0483	2,200	.....do	Sewage	16	3.5			40.1
							Effluent	3.2	.3	2	.1	3.6
Spencer	1897	.375	9.3	.0403	3,000	.....do	Sewage	1.5	4.5			46.5
							Effluent	1.2	.2	3.7	.2	3.3
Stockbridge	1899	.075	3.6	.0208	800	.....do	Sewage	9.8	1.6			15.2
							Effluent	0.9	.2	1.4	0	3.3
Westboro	1891	.282	4	.0705	3,000	Screening; partial sedimentation	Sewage	13.8	4.4			35.5
							Effluent	5.3	.7	3.6	.5	7.3
Worcester	1898	1.080	8.77	.123	122,000	Sedimentation	Sewage	18	8.1	.6	.1	138.7
							Effluent	10.9	.9	2	.3	18.1

[a] Worcester analyses of daily samples analyzed weekly from December 1, 1903, to December 1, 1904.

With regard to the comparative results of different Massachusetts plants the following points may be noted: The poor effluents at Westboro and Gardner are due partly to careless operation, the sewage being allowed to run on continuously for days. At Clinton the applied sewage is very strong. At Leicester, Andover, and Hopedale the board attributes results below the average to the fact that the sewage is stale or septic when applied. At Worcester the sewage is strong, and it is probable that its acid-iron waste interferes somewhat with the process of nitrification. It has been thought best, at any rate, not to attempt to treat crude sewage, as was done in the experiments included in Table XII. The comparative results of filtration with and without chemical precipitation, as shown in Table XIII, indicate the great advantage of special treatment.

TABLE XIII.—*Results of intermittent filtration of crude sewage and chemical effluent at Worcester, Mass. (Worcester, 1905).*

[Parts per million.]

Material.	Nitrogen as—					Oxygen consumed.	
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.	Total.	Soluble.
		Total.	Dissolved.				
Raw sewage	18	8.1	3.8	0.6	0.1	138.7	79.5
Sand effluent	10.9	.9	.9	2	.3	18.1	18.1
Chemical effluent	20.1	3.6	3.2	1.1	.4	56.5	44.4
Sand effluent	.8	.7	.7	4.1	.2	9.5	9.5

In construction the Massachusetts filters are simple, being built in general of natural glacial drift. The subsoil is removed, being used to form embankments between the beds, and the sand is not disturbed except for the laying of underdrains. Beds, as a rule, are 1 acre in area, the sewage being distributed through branched wooden carriers of sizes so varied as to secure approximately uniform distribution. This point is of much importance, since the passage of large volumes of sewage through a portion of a bed necessarily leads to poor results. At many plants, as at Framingham, Natick, and Brockton, crops have been grown on the beds. At Brockton this practice has recently been abandoned, since it was found to cause an accumulation of fine organic matter detrimental to the surface.

The effect of winter weather on the process has not been found to be serious. The actual freezing of the surface is prevented by furrowing the beds, so that a layer of ice forms on the top of the ridges, leaving an open space between them. Here the sewage flows, its warmth being sufficient to keep the surface open under the covering of ice. The process of nitrification is, however, considerably interfered with by the direct action of cold, as is shown on page 131 of this paper. This fact, combined with the impossibility of scraping off surface accumulations during severe weather, leads to a general clogging of the filters during the winter months. With ample capacity this period may easily be tided over. Goodnough said in 1904 (Winslow, 1905 b):

> Of the 15 sewage-disposal plants of considerable size where works were originally provided for the treatment of all of the sewage, all of the sewage is treated at all times at 6 places, or more than one-third of those having purification works, and very little sewage is discharged untreated at 6 of the remaining places, leaving only 3 places out of the 15 at which, at the present time, any considerable quantity of sewage is allowed to escape without treatment.

The accumulation of a certain amount of material on the surface of the beds is a necessary feature of the process of intermittent filtration as practiced in Massachusetts. This material, appearing in the form of a dry cake of a stable and inoffensive character, scarcely deserves the name of sludge, by which it is frequently designated. However, it necessitates a considerable expense in operation. The beds must be frequently raked and harrowed and occasionally plowed and scraped. At Pawtucket it has been found in ten years that for every million gallons of sewage 8.39 cubic yards of material (including sand) were removed from the surface (Pawtucket, 1904). At the Brockton plant, which is admirably designed and operated, full data are published on this point. In 1904 a daily flow of 900,000 gallons from a population of 40,000 was treated on 21½ acres of sand. A storage well at the pumping station holds the night flow of sewage, so that the pumps are run only in the daytime. The sediment which collects at the bottom of this reservoir is stirred up at the end of a run and discharged on four special "sludge beds." The cost of labor on the surface of all the beds during 1904 was $2,932, and the total cost of maintaining the area $4,412 (including gate tending, care of roadways, etc.), amounting to over $15 per million gallons (Brockton, 1905). The expense of maintenance at 16 Massachusetts plants varied in 1903 from $0.61 per million gallons at Natick to $21.92 at Stockbridge (Massachusetts, 1904). The Natick beds received practically no care except in connection with cropping, but operated satisfactorily. The next lowest figures were $2.45 at Pittsfield and $2.60 at Marlboro (large plants) and $2.87 at Concord (weak sewage). The costs at Clinton, Southbridge, Spencer, Westboro, and Worcester were between $3.91 and $7.80; at Gardner, over $9 at each of its two areas; at Brockton and Leicester, $11; and at Andover, $13.98.

TREATMENT OF SEWAGES IN THE SEPTIC TANK.

While the process of intermittent filtration was being scientifically developed in Massachusetts, English sanitarians were beginning to treat sewage on a totally different principle—that of anaerobic putrefaction. At an early period it had been noticed that in cesspools some action took place which led to the dissolution of solid matter. In Paris, where until 1880 various receptacles were largely used by individual householders for the reception of excreta, there might be found "the fosses fixées, from which the matter was raised by metallic vessels or vacuum pumps; the fosses sèches, used in the barracks; the tinettes filtres or filtrantes, which permitted the liquids to escape and reduced the refuse to one-fifth part, and the vidange automatique, invented by Mouras to do away with the necessity for even periodic removal of the solids" (Metcalf, 1901). The latter was "a closed vault with a water seal, which rapidly transforms all the excrementitious matter which it receives into a homogeneous fluid, only slightly turbid, and holding all the solid matters in suspension in the form of scarcely visible filaments." The action was attributed to anaerobic bacteria. This tank was introduced by Mouras about 1860, was fully described by Abbé Moigno in the Cosmos les Mondes in 1881, and was patented in 1882. In 1883 E. S. Philbrick, an American sanitary engineer, described a tank "in which the solid particles of the sewage may become macerated and finely divided by fermentation." In 1891 Scott-Moncrieff constructed at Ashtead, England, what he called a cultivation tank, in which sewage was allowed to pass upward through a tank containing stone prior to passage through "nitrifying channels" of coke. The attempt to produce a purified effluent failed, but it was shown that the first or anaerobic tank exerted a remarkable dissolving action on the solid constituents. In 1893 a plant on the same plan was designed for the borough of Towchester. A year later, in 1894, C. N. Talbot built a sewage tank at Urbana, Ill., in which the liquefying anaerobic action was observed; and a larger plant, with this definite end in view, was designed for Champaign, Ill., in 1895 and built in 1897.

The anaerobic process of sewage purification owes its practical development chiefly to Donald Cameron, of Exeter, England, who holds much the same relation to this process that the Massachusetts State board of health holds toward intermittent filtration. In 1895 he installed a water-tight covered basin for the treatment of the sewage of a portion of the city by anaerobic putrefaction and gave it the picturesque name of the septic tank. The sewage flowed slowly through the tank, taking about twenty-four hours in passage, the inlet and outlet being about midway between the top and bottom. He found that the liquid turned dark colored, while in the solids collected at the bottom an active fermentation was set up. Bubbles continually rose to the surface, carrying with them solid particles, which gathered at the surface to form a scum, sometimes so firm and compact that a man could stand upon it. This scum appeared and disappeared without any recognized reason. Meanwhile the effluent flowing off was freed from gross floating matter, and its total solids and organic constituents were decreased to one-half and two-thirds their initial value, respectively. The material removed did not, however, merely accumulate in the tank, which was operated for three years without cleaning. At the end of the first year 25 tons of solids had been removed from the sewage, of which it was calculated that 5 tons remained in the tank, and this in the form of a rather stable peaty deposit, only one-third organic in composition (Rideal, 1901).

The action in the septic tank is probably not the work of strict anaerobes, which appear to be rare in sewage, but of organisms able to grow either with or without the presence of oxygen. Under the latter condition the nature of their action is characteristic. They first decompose the solid materials by a lysis, which may or may not be hydrolysis (decomposition with the addition of water to the molecule). Next they decompose the dissolved molecule, producing gases on the [redacted] more stable peaty compounds on the other. Nitrogenous [redacted] partially reduced to gaseous nitrogen or free ammonia, and, together with cellulose, to carbon dioxide and marsh gas. The reaction is an exothermic one, evolving about 8 per cent as much heat energy as is left in the final products (Rideal, 1901). The amount of gas produced in the septic tank was found by Fowler at Manchester (1901) to be 7.5 gallons per 100 gallons of sewage, and Clark (1900) at Lawrence obtained concordant results. Kinnicutt and Eddy (1901), on the other hand, found less than half this amount (2.3 gallons) produced by the septic treatment of the acid-iron sewage of Worcester. The composition of the gas appears to vary widely at different places, but as a rule about three-fourths is methane and one-fifth free nitrogen. The amount of gas produced and, in general, the activity of septic action vary greatly with the temperature. Fig. 4, plotted from the data given by Kinnicutt and Eddy, shows this in a striking manner.

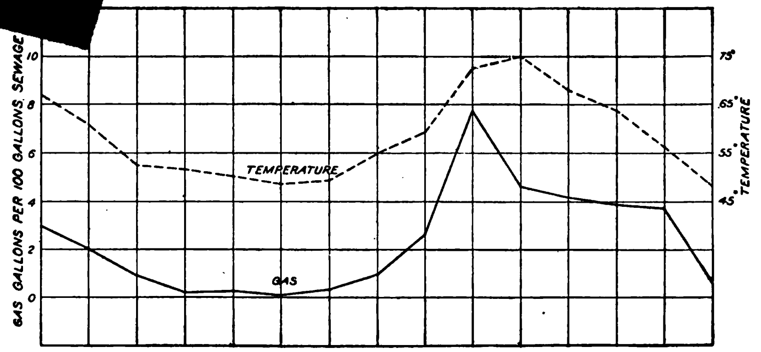

FIG. 4.—Seasonal variation in gas production in the septic tank.

The first septic tanks, like that at Exeter, were covered tightly. It soon appeared, however, that this type of construction is not at all necessary to the maintenance of anaerobic conditions. If sewage be merely allowed to run slowly through an open tank the general reactions appear to go on just the same. At Manchester the results from closed and open tanks under like conditions showed no marked difference, and in similar experiments at Leeds the open tank gave slightly better results, as shown in Table XIV. For promoting anaerobic conditions tight covers are therefore needless. Covering has been advocated in order that the gases produced may be utilized for burning and that the temperature of the sewage may be maintained. The burning of the gases is picturesque but not practically important, and the temperature of open tanks is never seriously lowered. At Leeds sewage in closed tanks lost 0.8°, in open tanks 1.6° F. For the prevention of odors and the fly nuisance and for protection against wind and rain a light frame roof may often be convenient.

TABLE XIV.—*Results from closed and open septic tanks at Leeds, England (Harrison, 1900).*

[Parts per million.]

	Solids.		Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	
Open tank:					
Crude sewage	1,710	633	23.6	11.3	124
Effluent	1,110	172	20.6	4.9	54.3
Closed tank:					
Crude sewage	1,720	666	25.5	12.4	131
Effluent	1,130	197	20	5	69.3

Scott-Moncrieff, in his Ashtead experiments, used, as already indicated, what was really a septic tank filled with stone. This principle has been applied in many other cases to the construction of anaerobic filters, lateral filters, etc., of various types. The so-called "ladder filters" tested at Leeds, formed by a series of trays of stone, from one to the other of which the sewage flowed continuously, operated on this principle--and very badly. At Salford, roughing filters containing one-fourth inch to 2-inch gravel were used for continuous filtration at a rate of 20 million gallons per acre per day. It was intended to wash these filters by upward flow with artificial aeration, but they have clogged seriously (Baker, 1904). At Lawrence a thorough study has been made of various strainers which operate with more or less continuous flow, of which further particulars are given in the second part of this report. All such devices, as well as the anaerobic filters installed at certain sewage plants in the Middle West, act like septic tanks, with the additional straining action due to the included material. Against this increased straining action must be set the tendency to clog and the difficulty of cleaning.

The most important point in the construction of a septic tank is its size in relation to the flow of sewage which is to pass through it. The tank is really a sedimentation basin in which the supernatant liquid and the settled sludge both undergo fermentation. The construction of special "hydrolytic" tanks, like that at Hampton (Baker, 1904), is gratuitous, since the bottom of the tank necessarily exhibits the hydrolytic phenomena to a high degree. The first requisite is that the period should be long enough to allow the maximum quantity of solids to settle out. From laboratory experiments on sedimentation it appears that this maximum is about 80 per cent and that it will be nearly reached by six hours' storage (Steurnagel, 1904). In practice it has often been found that a longer period is of advantage, perhaps for the liquefaction of suspended solids of too fine a character to settle out. The Leeds results in Table XV indicate an appreciably greater removal in twenty-four hours than in twelve hours, while further prolonging the period to forty-eight or seventy-two hours is of no advantage. The rules of the local government board require a septic-tank capacity of one and one-half times the dry-weather flow, and actual English practice generally contemplates a twenty-four hour period. At Birmingham the septic tanks proper accommodate only an eight-hour flow, but ten hours of additional storage are allowed in detritus tanks and a long conduit. Alvord (1902) and other American engineers provide shorter periods, often only four to eight hours, and some tanks operated on this principle, like that at Lake Forest, seem to work well. On the other hand, short periods of septic treatment at Wauwatosa and East Cleveland yield less satisfactory results (Winslow, 1905 b).

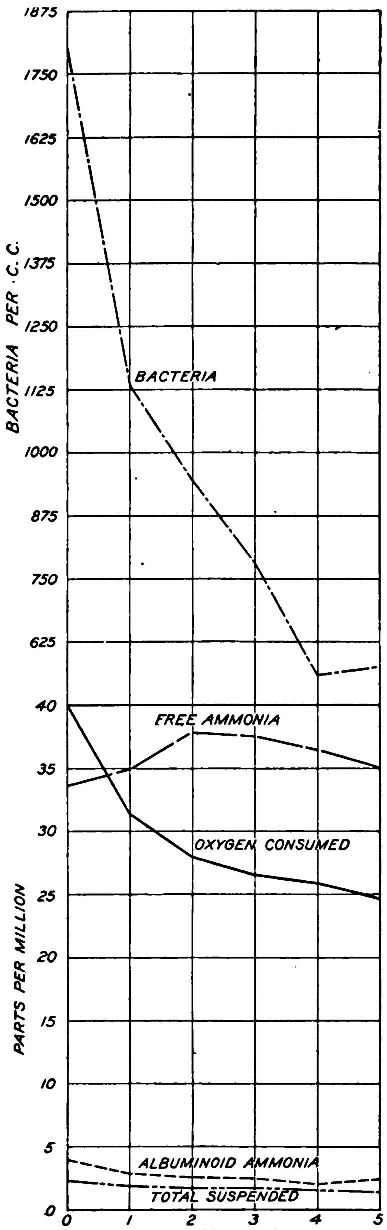

FIG. 5.—Progressive effect of septic action at Lawrence, Mass.

TABLE XV.—*Average of analyses illustrating the effect of different rates of flow through open septic tanks (Leeds, 1905).*

	12 hours' flow.		24 hours' flow.		48 hours' flow.		72 hours' flow.	
	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).	Parts per million.	Purification (per cent).
Total solids	1,250	....	1,110	....	1,120	....	1,050	....
Suspended solids	272	52	162	71	155	73	141	76
Nitrogen as—								
Free ammonia	18.2	22	17.5	24	18.8	19	20.8	37
Albuminoid ammonia	6.3	50	5.2	58	4.5	64	4	52
Oxygen consumed in 4 hours at 80° F	74.2	45	68.8	49	61.2	55	51.1	55

An interesting experiment was carried out at Lawrence on a small experimental tank with five successive compartments, each equivalent to one day's flow. The results are shown in Table XVI and are plotted in fig. 5. They indicate that although a steady change in the various constituents takes place the chief purification is accomplished in the first twenty-four hours.

TABLE XVI.—*Results of treatment of sewage in septic tank with five successive compartments, each holding one day's flow, April to December, 1903 (Massachusetts, 1904).*

	Analyses (parts per million).					
	Nitrogen as—				Oxygen consumed in 2 minutes' boiling.	Bacteria per cubic centimeter.
	Free ammonia.	Albuminoid ammonia.		Organic by Kjeldahl method.		
		Total.	In solution.			
Sewage	33.8	4.1	2.3	11.6	40.1	1,800,000
Effluent from first compartment (D-1)	36.1	3	2	....	31.4	1,100,000
Effluent from second compartment (D-2)	37.9	2.7	1.9	6.4	28	950,800
Effluent from third compartment (D-3)	37.5	2.6	1.8	....	26.6	800,000
Effluent from fourth compartment (D-4)	36.4	2.2	1.6	....	25.9	600,000
Effluent from fifth compartment (D-5)	35.1	2.4	1.5	5.3	24.7	600,000

The septic period should not be too prolonged, since, as will be seen later, the anaerobic fermentation, if carried too far, may produce an effluent difficult to nitrify. Furthermore, it is probable that even the anaerobic action itself may be checked by the concentration of waste products in too long a period. The marked decrease in bacteria in Table XVI indicates some such toxic action. An earlier Lawrence experiment is also suggestive. A small septic tank was dosed, not with sewage, but with the more concentrated sludge from settled sewage. For six months the storage period was from five to fifteen days and sludge accumulated, filling up 60 per cent of the tank. The rate was then increased, so that the storage period was reduced to forty-nine hours, when the accumulated sludge decreased to 8 per cent and did not further increase for a year (Massachusetts, 1901). At Leeds it was found that a seventy-two-hour septic period interfered with the solution of sludge (Leeds, 1905). Clark and Gage

(1905) have found that certain types of bacteria specially active in sewage purification increase during the first twenty-four hours of septic treatment and then fall to numbers smaller than are present in raw sewage. It seems possible that too long a period of action may actually favor the accumulation of sludge while producing an effluent hard to nitrify. Alvord (1902) for these reasons suggests the use of an "elastic tank" with separate compartments, which can be included in or thrown out of the system to adjust it to varying conditions of flow and temperature.

The results of septic treatment in three English cities and at Lawrence, Mass., are shown in Table XVII, and in Table XVIII is cited an interesting example of septic action on an intensive scale.

TABLE XVII.—*Effect of septic treatment.*

Place.	Material.	Solids.		Nitrogen as—		Oxygen consumed.		Remarks.
		Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Total.	Dissolved.	
Exeter	Sewage	778	350	44.4	....	29	....	April to June, 1897.
	Tank effluent	593	154	32.5	....	20.1	....	
Leeds	Sewage	1,690	622	24.7	11.7	127	....	February, 1899, to January 15, 1900.
	Tank effluent	1,090	183	21	5.2	58.5	....	
Birmingham	Sewage	1,967	676	31.9	13.7	153	76.1	Septic tank No. 1, 1901, open tank.
	Tank effluent	1,399	245	43.3	18.7	108	68.5	
Lawrence	Sewage	769	232	38.1	7	49.5	....	Tank A, January, 1898, to January, 1903.
	Tank effluent	597	107	37.7	3.3	27.3	....	

NOTE.—Oxygen consumed in four hours at 80° F. in the English results; in two minutes' boiling at Lawrence. Solids in Lawrence figures for year 1902 only.

Table XVIII shows the results obtained with an experimental tank at Brockton, Mass., in the treatment of very strong sewage pumped from the bottom of the receiving well during the last portion of the brief daily period of pumpage. The period of septic action was twenty-four hours. The results indicate a very high rate of purification. Bolling figures that of the suspended solids entering the tank 45 per cent remained as sludge, 6 per cent escaped in the effluent, 16 per cent went into solution, and 33 per cent disappeared as gas (Barbour, 1904).

TABLE XVIII.—*Results of treatment of sludge at Brockton, Mass., August and September, 1900 (Barbour, 1904).*

[Parts per million.]

Material.	Volatile residue.		Fixed residue.		Nitrogen as—			Oxygen consumed.	
	Dissolved.	In suspension.	Dissolved.	In suspension.	Free ammonia.	Albuminoid ammonia.			
						Total.	Soluble.	Total.	Soluble.
Sludge	229	1,810	271	555	34.5	42	3.9	396	74.5
Effluent	285	116	299	31	44.1	7.5	4.6	122	65.4

In comparing the work of the large English tanks, shown in Table XVII, it will be noticed that the effect on free ammonia varies, this constituent sometimes decreasing appreciably, as at Exeter, but generally remaining fairly constant. Sometimes, as at Worcester, it exhibits a marked increase. The reactions in the septic tank naturally vary materially with the original composition and age of the sewage. In a very fresh sewage there is always a considerable formation of free ammonia by the decomposition of more complex organic bodies. If this process has been completed when the sewage is subjected to septic treatment a decrease in free ammonia may be expected in the tank. Albuminoid ammonia and oxygen consumed in each case fall to one-half or two-thirds of their initial value. The evidence accumulated by the royal sewage commission indicated that an increase of free ammonia is the general rule in English septic tanks, while the albuminoid ammonia is reduced 38 to 54 per cent at Exeter, 50 per cent at Leicester, and 36 per cent at Birmingham. The oxygen consumed was reduced 25 to 33 per cent at Exeter, 50 per cent at Accrington, 50 per cent at Leeds, 36 to 60 per cent at Leicester, and 29 per cent at Birmingham (Martin, 1905). A curious phenomenon in certain septic tanks is the presence of oxygen or highly oxygenated compounds in the effluent in spite of the active reduction which takes place in the tank. Thus Barwise (1904) notes the occasional presence of nitrates and nitrites (up to 1 part per million) in the septic effluent at Exeter, and at Burnley after twelve hours' treatment in the septic tank oxygen was present to the extent of 1 to 3 per cent of saturation and nitrates up to 10 parts per million.

The most important practical result of septic treatment is the removal of suspended solids. Tanks at Exeter, Leeds, and Birmingham, as noted in Table XVII, show a reduction of 56, 71, and 64 per cent, respectively. At Leicester the removal has ranged from 60 to 70 per cent. At Lawrence 181 parts per million of suspended solids were reduced to 73 parts, a removal of 61 per cent (Massachusetts, 1904). Experiments on London sewage at the Crossness outfall showed that six hours' sedimentation in what was really a septic tank gave a reduction from 281 to 125 parts of suspended solids (November, 1900, to March, 1901) and in another series (March to October, 1901) from 253 to 143 parts, a removal of 56 and 43 per cent, respectively. These London results illustrate the gradual increase in suspended solids discharged in the effluent, which is sometimes noticed during the first year of a tank's operation. At Leeds 127 parts appeared in the septic effluent from March to June, 1899, 156 parts from July to October, and 213 parts from November, 1899, to February, 1900 (Leeds, 1900). At Huddersfield the septic effluent contained 66 parts in August, 1900, 82 parts in September, 113 parts in

October, 122 parts in November, and 117 parts in December (R. S. C., 1902 b).

The action of the septic tank on dissolved solids is a variable one, as shown in Table XIX, taken from Kinnicutt, with the addition of figures from a recent Lawrence report.

TABLE XIX.—*Removal of solids by the septic tank* (*Kinnicutt, 1902; Clark, 1904*).

Place.	Solids removed (per cent of total).	
	Dissolved.	Suspended.
Exeter	− 2.57	56.01
Lawrence	2.12	61.60
Leeds	12.05	70.37
Manchester	15.45	57.06
Worcester	20.67	25.57

It will be noticed that a slight removal of dissolved solids occurs, except at Exeter, reaching a considerable amount at Worcester. The phenomena in the case of Worcester are peculiar on account of the acids and iron salts in the sewage. In the first place all the reactions are hindered by the antiseptic action of these substances. The reduction of albuminoid ammonia is small, only 20 to 25 per cent, the gas production is only half that at Lawrence and Manchester, and the liquefaction of sludge is imperfect. In the second place the proportionate decrease of suspended solids is small and of dissolved solids great on account of the reduction and precipitation of iron compounds.

Granting that the septic tank effects a removal of 60 to 70 per cent of suspended solids under favorable conditions, the fate of the matter retained must next be determined—how much is stored as sludge and how much is reduced to liquid or gaseous form. Evidence before the royal sewage commission indicates a destruction of the stored solids, amounting to 26 per cent at Manchester, 25 per cent at Birmingham (too low a figure, since a great deal of reducible sludge is removed from sedimentation chambers cleaned out weekly), 20 to 60 per cent at Leeds, 30 per cent at Sheffield, 35 per cent at Accrington, 40 per cent at Huddersfield, 50 per cent at Glasgow, and 80 per cent at Exeter (Martin, 1905). At Saratoga the septic tank destroys 40 per cent of its sludge (Barbour, 1904). This value will naturally vary widely according to the ratio of organic to inorganic solids in the sewage, the inorganic solids being much less likely to disappear. In the London experiments the destruction of total sludge was 41 per cent and of organic sludge 71 per cent (Dibdin, 1903). At Hampton 58 per cent of the organic sludge was destroyed (Baker, 1904).

Practical experience with septic tanks yields widely varying results with regard to the destruction of stored solids, as indicated by the necessity for emptying the tanks and removing sludge. At Exeter

Cameron's original tank was operated for eight years without cleanng, but from the present installation, with a fourteen-hour period, ludge is pumped out once a month. At Barrhead a tank has been n use for six years (twenty-four-hour period) without cleaning and with little deposit. At Acton (sixteen hours) a tank has been operated for fifteen months with no deposit. At Yeovil (twenty-four hours), Burnley (twelve hours), Sutton (five hours), and Accrington (twenty-eight hours) it has been found necessary to remove sludge about once a year. At Oldham the tank is cleaned every two or three months (Baker, 1904). American plants exhibit similar variations. The Lawrence tank has not been cleaned for six years, and in 1903 was less than half full of accumulated sludge. At Marion a twenty-hour tank worked for two and one-half years without emptying. At Mansfield, with a twenty-four-hour period, admirable results have been obtained, only an insignificant amount of sludge having accumulated after three years of use. At Plainfield solids accumulate in the form of scum rather than sludge and are removed several times a year. Sludge and scum are probably largely interchangeable, a slight difference in specific gravity determining the destination of the solids (Barbour, 1904). At Lake Forest (four hours), the tank has been operated for three years without cleaning, while at Wauwatosa (ten hours) the tank is emptied twice a year (Winslow, 1905 b). Of conditions in Ohio, Pratt (1904) said in 1903:

> There are now in use 10 septic tanks, while plans for 14 more have been made. The present tanks have been in operation from one to five years. As sludge destroyers they have been fairly successful, but in a few cases offensive odors are created, and in some the effluent from the tank is probably not in the best possible state for subsequent oxidation in the filters. As far as can be learned the tanks have continued in use from one to two years without decreasing in capacity more than 25 per cent. The scum formed at the surface and bottom accumulation appears to remain fairly constant after reaching a certain volume; but a change in the composition of the sewage or in other conditions may cause a rapid increase in the deposits.

On the whole, it seems necessary to conclude with Baker (1904) that "in the majority of septic tanks thus far built for municipalities the sludge must be removed at intervals of a year or less." In certain special cases, as at Exeter and Mansfield, unknown conditions intervene to cause a more complete destruction of the stored solids.

The chief purpose for which the septic tank has been introduced is the diminution of suspended matter and the consequent lightening of the sludge burden. It is claimed by some experts that in addition to this action the anaerobic putrefaction brings the soluble constituents into a form in which they are more easily acted on by the nitrifying organisms. Martin, Cameron, and Fowler all expressed this opinion before the royal sewage commission (Martin, 1905). The writers are not aware of any data which support this contention. Harding and Frankland (Martin, 1905) are skeptical as to such an advantage and Dibdin (1904) wholly disbelieves in it. On the other hand, it is probable, as was shown before the royal sewage commission, that when not accurately regulated, "the anaerobic process may be carried too far, so as to interfere with the subsequent aerobic action" (Dibdin, 1903). Martin and Rideal minimize such interference, while Scott-Moncrieff, Woodhead, and Fowler consider it of great importance (Martin, 1905). It appears certain that with strong sewage the putrefactive process may be carried so far that its products will check the aerobic organisms. In experiments at Caterham an effluent was obtained containing 1,260 parts per million of dissolved solids, 288 parts of nitrogen as free ammonia, and 53 parts of organic nitrogen, which would not undergo nitrification until diluted (Rideal, 1901). Experience at Andover leads to the same conclusion. Here the sewage is strong and already twenty-four hours old when it reaches the disposal area. Most of it is discharged on sand beds without further treatment. While the beds were successfully handling raw sewage at a rate of 0.03 million gallons per acre per day, a small filter gave poor results with septic effluent at a rate of 0.04 and very bad results when the rate was increased to 0.1 (Clark, 1900).

From a general review of the results cited above it is not easy to determine just how much is to be gained by the introduction of the septic tank in a sewage-disposal system. With a small plant receiving very fresh sewage from a small town or an institution, it is of great advantage in breaking up masses of fecal matter. In such plants and in those which handle considerable quantities of manufactural waste the equalization of flow and composition may be of much importance. The latter factor, for example, carried weight at Manchester. These, however, are special cases. The chief point is that by proper septic treatment 60 to 70 per cent of the solids in sewage may be removed. When such a removal is necessary before final aerobic treatment, the septic tank will generally be found the best means for effecting it. Compared with chemical precipitation it has the advantage that its sludge is less in amount, besides the fact that the cost of chemicals is saved. Experiments at Oldham (R. S. C., 1902 b) pointed clearly to the superiority of the treatment without chemicals, and at Birmingham the substitution of septic tanks for precipitation resulted in a saving of $20,000 per annum and a decrease of 25 per cent in sludge (Watson, 1903). Whether any preliminary removal of solids is always desirable before final aerobic treatment is believed to be by no means certain. English authorities strongly tend to the opinion that such treatment is necessary. Rideal (1901) holds that an anaerobic stage is necessary in the process of sewage purification, although he admits that it may be accomplished in long sewers without special treatment. Ward and Woodhead maintain that the destruction of cellulose in particular can be accomplished only under anaerobic conditions (R. S. C., 1902). Scott-Moncrieff, Whittaker, Stoddard, and Fowler (Martin, 1905) all hold the process to be necessary. The practical data on which these conclusions are chiefly founded are discussed on pages 63–64. These data are in general the results of experiments at Leeds, Manchester, and other cities which showed that aerobic filters of large material, worked as contact beds, tended to clog badly when treated with crude sewage, while they worked well if the sewage was previously septicized. Experiments on coarse filters through which sewage is allowed to trickle continuously have suggested, on the other hand, that crude sewage may sometimes be successfully treated at rapid rates and settled later after it has been nitrified. There are numerous examples in nature of the destruction of organic matter by purely aerobic processes. Even cellulose is most actively attacked just at the surface of the ground, as evidenced by the decay of fence posts. Dibdin (1904), almost alone among the English sanitarians, has recently taken a strong position against the theory that the decomposition of cellulose must necessarily be anaerobic. The writers are of the opinion that the anaerobic process has not been shown to be a universally necessary step in the process of purification. In many plants it will no doubt prove useful. In other cases, however, a short preliminary sedimentation without septic action or subsequent sedimentation of a trickling effluent obtained by the treatment of crude sewage may be more economical.

In the eastern part of the United States, where ample areas of sand of the right quality are available for intermittent filtration, the use of the septic tank is rârely held to be necessary. In most cases the solids are discharged directly on the surface, where they are partly oxidized and partly accumulate as sludge. In the Middle West, on the other hand, where sand areas are limited and rates must be high, the use of the septic tank is very general. Barbour, Alvord, and Shields are all strong advocates of the practice, and the plants they have installed work very satisfactorily at higher rates than those in use with raw sewage in Massachusetts. At Saratoga (Barbour, 1905) the rate is 0.1, at Lake Forest it is over 0.4, and at the Wauwatosa county institutions 0.4.

PURIFICATION OF SEWAGES BY THE CONTACT PROCESS IN BEDS OF COARSE MATERIAL.

It has been shown that the scientific development of the process of purifying sewage by the action of oxidizing bacteria really dates from the experiments conducted at Lawrence, Mass., under the direction of Hiram F. Mills. The direct application of the method of intermittent filtration is, however, rather narrowly limited by local conditions. In many regions the cost of constructing sand filters of sufficient area to treat sewage at a rate of 0.1 million gallons per acre per day would be entirely prohibitive. For England, in particular, it was necessary to modify the process so as to obtain higher rates of filtration, even at the cost of a lower purification. This was first accomplished in a practically effective manner in a series of experiments carried out at Barking for the London county council, the attainment of a high rate being made possible by the use of materials coarser than sand. Almost insensibly this changed the whole conception of sewage purification. With coarse material there was little true "filtration," and it became evident that the bed was really not a filter, but an oxidizing machine. Frictional resistance could no longer be depended on to delay the flow through the bed sufficiently to allow purification to occur. It was necessary, therefore, to regulate the rate by constructing water-tight filters, in which the sewage could be retained in contact with the filling material and its accumulated growth of micro-organisms. Hence this type of purifying plant was called the "contact bed." It operated with success, attracted wide attention, and inspired the design of numerous so-called "biological filters" on similar principles.

W. J. Dibdin, chemist to the London county council, was one of the first English sanitarians to grasp the essential principles of sewage purification. In studies of the self-purification of the Thames, H. C. Sorby had pointed out as early as 1883 the part played by living organisms, although he had in view chiefly the consumption of solids by the larger microscopic forms. In 1884 Dupré went a step further in affirming the relation of organic life to the oxidations which take place in a purifying stream. Didbin, who had been associated with both these observers, read a paper before the Institution of Civil Engineers in 1887, in which he worked out the whole theory as follows:

> In all probability the true way of purifying sewage, where suitable land is unavailable, will be first to separate the sludge, and then to turn into the effluent a charge of the proper organism, whatever that may be, specially cultivated for the purpose, and retain it for a sufficient period, during which time it should be fully aerated and finally discharged into the stream in a really purified condition. This, indeed, is only what is aimed at and imperfectly accomplished on a sewage farm. [Dibdin, 1903.]

The treatment of London sewage by chemical precipitation alone was recognized by the metropolitan sewage commission in 1884 as only a temporary expedient, a final treatment on land being contemplated. As soon, therefore, as the Massachusetts results were published Dibdin saw their importance and began a series of investigations on the treatment of sewage on the Lawrence principle, but at more rapid rates. His first series of investigations was carried on between May and August, 1892, to determine the best material to employ. Four wooden tanks were installed at the northern (Barking) outfall. Each was 5 feet deep and had an area of one two-hundredth of an acre, and they were filled, respectively, with burnt clay, pea ballast (Lowestoft shingle), coke breeze, and a combination of gravel and sand over a layer of proprietary material. All received effluent from the chemical precipitation tanks at an average rate of 0.4 million gallons per acre per day. Sewage was allowed to run through continuously for eight hours, the rate being controlled by partially closing the outlet valves, and the beds were allowed to stand empty for aeration during the remainder of the twenty-four hours. The coke breeze, as indicated in Table XX, proved most satisfactory, the coarser burnt clay yielding a much poorer effluent, and the sand clogging seriously and giving a clear but imperfectly purified filtrate.

TABLE XX.—*Results of filtration through various coarse materials, London experiments, first series, May to August, 1892 (Clowes and Houston, 1904).*

[Parts per million.]

	Oxygen consumed in 4 hours at 80° F., filtered.	Albuminoid nitrogen.
Chemical effluent	20.1	2.7
Effluent from filter No. 1 (burnt clay)	11.6	1.3
Effluent from filter No. 2 (pea ballast)	9	1.3
Effluent from filter No. 3 (coke breeze)	7.2	1.1
Effluent from filter No. 4 (sand, etc.)	7	.8

Coke breeze was fixed on as the best material for further experiments, and a second series was begun to study the details of practical operation on a larger scale. A filter bed 1 acre in area, consisting of 3 feet of pan breeze covered with 3 inches of gravel, was constructed at Barking and put into operation in September, 1893. At first the bed was dosed too heavily and soon became clogged and foul. The need for rest and aeration, especially when a new filter is first operated, was thus clearly shown. After three months' rest the bed could handle two fillings a day, the sewage being allowed to stand in it for a period of from one to two hours. The cycle finally established allowed one and one-half hours for filling the bed, two hours for standing full, two and one-half hours for emptying, and six hours for aeration. When gradually worked up to its full capacity sewage could be treated at a rate of 1.2 million gallons per acre per day; the purification effected by the filter suffered no reduction with age; and the analytical results were excellent, as indicated in Table XXI.

ABLE XXI.—*Results of contact treatment at London, acre filter* (*Clowes and Houston, 1904*)

[Parts per million.]

Period.	Oxygen consumed in 4 hours at 80° F.		Nitrogen as—			
			Free ammonia.		Nitrates.	
	Chemical effluent.	Filter effluent.	Chemical effluent.	Filter effluent.	Chemical effluent.	Filter effluent.
eptember–December, 1893	59	17	4.8	1.4	1.6	1.9
pril–June, 1894	59	12	4.9	1.1	1.8	3.4
uly–November, 1894	52	10	4.7	1.3	.3	2
anuary–March, 1895	61	14	4.8	1.4	5.4	9.7
pril–September, 1895	46	9	4	1.3	2	7.6
ay–June, 1897	31	6	3	.9	.6	4.1
00–1901	55	9	....	....	.4	10

The early London experiments of Dibdin have been greatly extended ince 1898 by Clowes and Houston. Various details of construction and peration were worked out at both the Barking and Crossness outalls, and the recommendation was finally made that the present plan f chemical treatment be abandoned and that the London sewage be, irst, settled to remove gross mineral matter; second, septicized for ix hours; and, third, treated in single contact beds of coke, 12 feet eep, at a rate of 5.2, attained by four fillings per day (Clowes and Iouston, 1904).

In 1894, as a result of the first Barking experiments, Dibdin intalled seven experimental contact beds at Sutton, in Surrey. Here wo important modifications of the contact system were introduced. n the first place, the sewage was subjected to successive treatients, first in coarse and then in finer-grained beds—the "double ontact" system. In the second place, after the process had worked ell with chemical effluent, as it had done at London, the treatment f crude sewage was attempted. Beginning November, 1896, a ouble-contact system treating crude sewage was operated for the rst time. The depth of the beds was 3 feet 6 inches, and the filling iaterial burnt ballast, larger than three-eighths inch. Two fillings day were made, giving a rate on each individual bed of 0.9. The nalytical results showed a reduction of oxygen consumed from 76 arts per million in the sewage to 26 parts in the effluent of the first ed and 10 parts in the effluent of the second bed (Dibdin, 1903). he system worked for five years with admirable results. At presnt sewage is carefully screened (2 to 3 tons of solids per million galons being removed) and then treated in primary coarse beds of burnt allast and secondary fine beds of coke breeze, at a combined rate based on the area of both sets of beds) of 0.36. It is calculated that he cost of operation is only about $20 per million gallons, as against 75 for the original treatment with iron sulphate and lime (Rideal, 901).

The general principles of the contact system being thus established, it becomes necessary to work out details of construction. One of the first of these details concerns the nature of the filling material. In the Sutton tanks it was found that burnt clay gave somewhat better results than the other substances, although it tended to break down badly. Granite and slate proved more permanent (Thudichum, 1903). The important series of experiments carried out at Barking and Crossness in 1898–1901 showed that for treating London sewage coke was preferable to stone, as indicated in Table XXII.

TABLE XXII.—*Results of contact treatment at London (Barking), 1898–1901 (Clowes and Houston, 1904). Analyses of effluents.*

[Parts per million.]

Period and treatment.	Suspended solids.	Oxygen consumed in 4 hours at 80° F.		Nitrogen as—	
		Total.	Dissolved.	Nitrites.	Nitrates.
September, 1898, to April, 1899:					
Crude sewage		145	54	0.2	1.3
Double contact, ragstone, 6 feet		32	28	1.6	21.7
Double contact, coke, 6 feet		24	20	.7	12.5
July 4–15, 1899; Sept. 21, 1899, to May 19, 1900:					
Crude sewage	661	124	63	.2	1.1
Double contact, coarse coke, 10 feet	73	38	23	1.2	10.2
Double contact, coarse and fine coke, 10 feet	31	23	18	.6	21.8
Nov. 7, 1900, to Aug. 10, 1901:					
Crude sewage	667	129	68	.1	.4
Septic tank A	177	84	54	.0	1.7
Coarse coke bed, 6 feet	100	51	33	.4	7.5
Septic tank B	139	82	53	.0	1.3
Fine coke bed, 6 feet	32	37	76	.6	12.9

Dibdin and Thudichum report a series of studies summarized in Table XXIII which again indicate the superiority of coke.

TABLE XXIII.—*Comparison of filtering material (mean values) (R. S. C., 1902 a). Analyses of effluents.*

[Parts per million.]

Material.	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Free ammonia.	Albuminoid ammonia.	
Coke	16.6	0.58	0.94
Coal	23.4	1.04	1.52
Glass	23.8	.12	1.55

At Lawrence, also, by far the best results have been given by coke. Rough materials give better qualitative results than smooth materials. Broken-stone filters have not been particularly efficient (Massachusetts, 1903). The general results obtained at Lawrence on single-contact filtration are shown in Table XXIV.

TABLE XXIV.—*Results of single-contact treatment at Lawrence, Mass.* (*Fuller, 1905*

No. of filter.	Material.	Depth (inches).	Preliminary treatment.	Rate (million gallons per acre per day).	Analyses (parts per million): Sewage: Nitrogen as—: Free ammonia.	Sewage: Nitrogen as—: Albuminoid ammonia.	Sewage: Oxygen consumed.	Effluent: Nitrogen as—: Free ammonia.	Effluent: Nitrogen as—: Albuminoid ammonia.	Effluent: Nitrogen as—: Nitrates.	Effluent: Oxygen consumed
103	⅛- to ¼-inch coke.	60	Septic..	0.6	38.7	3.3	27.3	7.9	0.9	21.2	[illegible]
107	Cinders	24	None...	.55	23.8	4.6	34.5	13.4	1.7	5.4	15
135	¼- to 1-inch stone	214	None...	1.2	37.8	5.6	49.5	20.3	1.7	3.4	13.3
154	Coke, breeze	48	Septic..	.5	58.7	6.6	45.4	42.3	2.2	3.0	14.
167	Stone (walnut).	48	Septic..	.3	85.3	8.5	65.9	64.6	3.2	13.4	20.
176	¼- to 1-inch coke.	60	None...	.7	37.2	6.1	42.8	13.1	1.5	11.3	[illegible]

At Birmingham it was found that the purification, measured by reduction in oxygen consumed, was 64 per cent with broken stone, 71 per cent with slag, and 93 per cent with coal (Bredtschneider and Thumm, 1904). There is some evidence (see p. 82) that coal exerts a specially favorable action in trickling filtration (Hill, 1897). At Manchester (1901) materials containing iron were found to yield particularly good results. At Hamburg it appeared that the amount of porosity is immaterial and that the chief desideratum is iron content. Thumm, by the addition of 1 per cent iron to gravel or pumice, increased the purification in two contact beds from 46 and 42 to 66 and 62 per cent, respectively (Thumm, 1902).

A series of experiments on various materials conducted by Zahn at Charlottenburg in 1901 showed that brick gave the best results, followed by slag, coal, coke, and gravel in the order named. The results are brought together in Table XXV. In each case the secondary sand filter was operated as a contact bed, the sewage standing on it under a head during the full period. It acted chiefly as a strainer to remove suspended solids.

TABLE XXV.—*Results of Charlottenburg experiments on contact filtration* (*Zahn, 1903*).

[Parts per million.]

	Total solids.		Suspended solids.		Nitrogen as—			Oxygen consumed in 10 minutes' boiling.
	Total.	Loss on ignition.	Total.	Loss on ignition.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Raw sewage	1,121	294	413	272	65	19	0	118
I. a. Slag	1,059	163	82	54	22	11	Present...	64
I. b. Sand	1,068	149	0	0	17	7	.....do....	30
II. a. Coke	1,028	159	38	22	36	9	.....do....	66
II. b. Sand	1,044	177	0	0	24	7	.....do....	[illegible]
III. a. Gravel	1,084	203	101	68	32	12	.....do....	[illegible]
III. b. Sand	1,137	235	0	0	20	6	.....do....	52
IV. a. Brick	1,229	173	39	20	21	8	.....do....	38
IV. b. Sand	1,280	204	0	0	18	8	.....do....	[illegible]

In general, these results with regard to kind of material are somewhat inconclusive. Coke and coal seem particularly favorable and the presence of iron is apparently important. Cameron and Harding consider smoothness of surface desirable (R. S. C., 1902 a), but this conclusion is scarcely borne out by the successful use of coke.

The nature of the material used will necessarily depend much on local conditions. Its size is more a matter of choice and this factor is of even greater practical importance. Reference to the Hamburg results in Table XXVIII illustrates this point. It will be noticed that one-eighth to five-sixteenths inch material in experiments B and C gave twice as much purification as three-eighths to 1⅛ inch material in experiments L, M, N, and P. The high purification in these beds was, however, accompanied by great loss of capacity. At the royal testing station at Berlin, it was found in experiments with several different sewages that one-third to 1 inch slag for the first contact and one-eighth to one-third inch slag for the second contact gave the best results. The primary beds effected a purification of 20 to 30 per cent. The secondary beds raised this figure to 70 per cent and produced a nonputrefactive effluent (Thumm, 1902). Clowes and Houston (1904), as a result of their London experiments, recommended the use of "walnut-size coke." In evidence before the royal sewage commission, Fowler recommended one-eighth inch material, Cameron one-eighth to one-half inch, Frankland one-eighth to three-fourths inch, and Dibdin one-half to 4 inch for first contact and one-sixteenth to three-eighths inch for second contact (Martin, 1905). Barwise (1904) suggests the use of coarser filling—3 to 5 inch material for primary beds and one-half to 1½ for secondary beds to treat septic effluent. An interesting suggestion has recently been made by Dibdin (1904), who recommends the construction of "multiple-surface bacteria beds" of tiers of slate or brick regularly built up so as to secure a liquid capacity sometimes reaching 80 per cent. A bed built at Devizes on this plan is said to have cost less than one-third as much as an ordinary coke bed. Analyses from such a bed are shown in Table XXVI.

TABLE XXVI.—*Results from multiple-surface bacteria bed, February 9 to March 25, 1904 (Dibdin, 1904).*

Average number of fillings per day		0.83
Nitrogen as albuminoid ammonia:		
In sewage	parts per million	9.9
In effluent	do	4.8
Oxygen consumed in 4 hours at 80° F.:		
In sewage	do	76.6
In effluent	do	58.7

If a bed were filled with perfect spheres of uniform size its open space or water capacity would be 26 per cent of its original cubic capacity. In beds built of the ordinary materials actually used this value varies from 30 to 50 per cent. With progressive use the capacity decreases, and this is one of the most serious problems in the operation of the contact bed.

In an admirable analysis of the causes which affect the loss of capacity in contact beds the Manchester experts (Manchester, 1902) arrange them under the following five heads:

(*a*) Settling together of the material.
(*b*) Growth of organisms.
(*c*) Impaired drainage.
(*d*) Insoluble matter entering the bed.
(*e*) Breaking down of the material.

The first cause must always operate to a considerable extent and in part accounts for the great initial loss when the bed is first put in operation. If the original liquid capacity is determined, not by filling with water and measuring the effluent, as should be done, but by measuring the amount of water or sewage required to fill it, the initial loss will appear much larger than it really is, by the amount of water required to saturate the surfaces and pores of the dry material. The relative importance of this initial loss and of the true loss due to settling, growth, etc., is indicated in Table XXVII.

TABLE XXVII.—*True and apparent loss of capacity in a contact bed* (*Martin, 1905*).

	Capacity.	
	Gallons.	Per cent of total.
Total cubic contents	23,431	100
First filling, Aug. 15, 1896	13,775	59
Filling Aug. 21, 1896	10,302	44
Filling Nov. 14-15, 1896	7,893	34

The actual decrease in capacity after the first filling is partly due, as noted above, to the breaking down of uniform materials into pieces of more varied size which become more closely packed together. The amount of this loss may be measured by the space left by the settling over the top of the material. At Pawtucket it was estimated that about one-third of the total capacity loss in eighteen months was due to this factor. Such loss may be avoided to a great extent, as has been pointed out above, by the use of compact and permanent filling. This was shown very clearly in the Hamburg experiments. Table XXVIII shows, by a comparison of experiment G with H and I and of experiment N with M and O, that slag, while giving as good analytical results as coke and gravel, showed appreciably less loss of capacity.

TABLE XXVIII.—*Statistics of Hamburg experiments on contact filtration* (*Dunbar and Thumm, 1902*).

No. of experiment.	Material.		Kind of sewage received.	Number of fillings per day.	Length of run (months).	Oxygen consumed in 10 minutes' boiling.		Capacity (parts per million).		Remarks.
	Kind.	Size (inches).				Sewage.	Effluent.	Original.	Final	
B......	Slag......	1/8 to 5/16	Raw..................	1	26	96	27	33	20	
C......	.....do....	1/4 to 5/16	.....do................	2	14	91	21	41	15	
L......	Coke......	3/8 to 1 1/8	.....do................	6	15	80	52	38	[a] 30	Washed twice.
D......	Slag......	1/8 to 5/16	Effluent from L......	3	15	80	20	43	17	
E......	Gravel....	1/8 to 5/16	.....do..............	2	11	80	19	27	14	Washed once.
F......	Coke......	1/8 to 5/16	.....do................	2	15	80	19	36	22	
G......	Slag......	3/16 to 3/8	Effluent from N.....	3	11	90	30	39	23	
H......	Coke......	3/16 to 3/8	.....do................	3	11	90	27	39	22	
I......	Gravel....	3/16 to 3/8	Effluent from M (4 months) and P (7 months).	3	11	90	28	31	19	
K......	Gravel + 1 per cent iron turnings.	3/16 to 3/8	Effluent from M.....	3	11	90	29	31	19	
M......	Coke......	3/8 to 1 1/4	Raw..................	3 to 6	12	88	63	44	28	
N......	Slag......	3/8 to 1 1/4	.....do................	3 to 6	12	88	65	48	39	
O......	Gravel....	3/8 to 1 1/8	.....do................	3	12	88	46	35	26	
P......	Brick.....	3/8 to 1 1/8	.....do................	3	12	88	46	44	28	

[a] Fell to 18 per cent before last washing.

In England the loss of capacity due to breaking down of material has been found to be serious with clay not thoroughly burnt, and the need for permanent filling has led to an extensive use of various sorts of furnace clinker. Many English beds are, however, still built of friable stuff. Baker (1904) says: "It seems strange to an American to see so much perishable material used for filter beds," and suggests that in the United States gravel or broken stone will probably be preferable to cinders, clinker, or brick.

The capacity loss due to impaired drainage, like that from the breaking down of material, may be controlled to some extent by proper construction of the beds. The other two losses, due to growths and to deposition of solids, are more or less inevitable.

The loss of capacity due to the growth of organisms is more or less directly correlated with an increasing purifying power of the bed. At Manchester it was found that "the chemical efficiency is increased by a loss of capacity. These beds purified four doses after they had become partly clogged as readily as three when clean. The amounts were about the same in the two cases." (Manchester, 1899.) Dunbar gives the figures quoted in Table XXIX to illustrate this point. He considers that the ability of the filter to absorb rapidly free ammonia from the sewage is an index of the amount of growth within the filter.

TABLE XXIX.—*Improvement in ammonia absorption in a contact filter (Dunbar and Thumm, 1902).*

Months at work.	Loss in ammonia (per cent).	
	Single filling.	Double filling.
1	9.1	14.6
2	34.6	30.9
5	35.2	23
8	47.4	41.3
10	43	41.2
14	40.5	41.6

This sort of loss due to growth is almost independent of the character of the liquid filtered. Dunbar treated coke contact filters with various substances (134 fillings in four months) and found with tap water a reduction in capacity from 48 to 40 per cent; with tap water plus 1 per cent urine, from 47 to 37 per cent; with unfiltered sewage from 48 to 37 per cent; with filtered sewage, from 48 to 40 per cent, and with sewage precipitated with lime, from 44 to 36 per cent (Dunbar and Thumm, 1902).

The loss of capacity due to the deposition of the insoluble mineral matter which enters the beds is also serious and in England has necessitated the complete renewal of many contact filters. It may be avoided to a considerable extent by preliminary straining and sedimentation, and it tends to be concentrated in the upper layers of the filter. With some sewages, however, it seems clear that contact filters will require frequent renewal. The experiments at Leeds furnish a good example of this. Table XXX indicates a reduction to values as low as 9 and 11 per cent. It appeared evident to the experts in this case that in order to treat Leeds sewage in contact beds it was necessary to use an even, hard filling material, to remove suspended mineral matter by careful sedimentation, and to exclude iron compounds from the sewers. Even then they considered the permanency of the beds more than doubtful.

TABLE XXX.—*Loss of capacity in contact beds at Leeds—raw and settled sewage (Leeds, 1905).*

No. of bed.	Material.	Period.	Original capacity (per cent).	Final capacity (per cent).
1	Coke, not less than 3 inches	Oct. 2, 1897, to Oct. 7, 1899	48	15
3	Clinker, ½ to 1 inch	Nov. 19, 1898, to Jan. 10, 1901	51	14
5	Clinker, 1 to 2 inches	Feb. 27, 1899, to Dec. 30 1900	52	11
7	Clinker, ⅝ to 1 inch	Mar. 8, 1899, to Feb. 15, 1901	31	9
8	Clinker, ⅜ to 1 inch	Mar. 30, 1898, to Sept. 1, 1899	31	12

It is possible to restore the original capacity of contact beds to a considerable extent by allowing them to rest empty for several weeks Table XXXI shows how efficient this process was at York and at Leeds in the case of two of the beds above referred to. Rest can of ourse effect only the disintegration of the organic growth and can not ffect the accumulated mineral matter. The restoration of capacity an therefore never be complete.

TABLE XXXI.—*Loss in capacity of contact beds and its recovery by resting.*

NABURN DISPOSAL WORKS, YORK (YORK, 1901).

	U. S. gallons.	Per cent open space.
Bed No. 1.		
ubic capacity	55,200	100
itial liquid capacity	22,300	40
fter 90 days' work	11,200	20
fter 14 days' rest	16,400	30
fter 42 days' work	11,500	21

KNOSTROP SEWAGE WORKS, LEEDS (LEEDS, 1900).

	U. S. gallons.	Per cent open space.
Bed No. 7, single contact.		
ubic capacity	222,000	100
nitial liquid capacity	66,800	31
fter 226 days' work	25,900	12
fter 74 days' rest	64,200	30
fter 184 days' work	30,700	14
Bed No. 8, single contact.		
ubic capacity	113,000	100
nitial liquid capacity	35,400	31
fter 185 days' work	12,800	11
fter 50 days' rest	32,300	28
fter 203 days' work	11,800	10

The treatment of septic effluent instead of crude sewage greatly prolongs the life of the contact bed. In the Barking experiments (Clowes and Houston, 1904) the capacity of two primary coke beds fell in ten months from 69 and 70 per cent to 20 and 18 per cent, respectively. Secondary beds showed only a reduction from 62 to 51 per cent (coarse) and from 53 to 44 per cent (fine). The stone beds lost about 1 per cent of their original liquid capacity per week. A series of experiments with septic effluent followed, in which after the first loss a capacity of about 30 per cent was constantly maintained. At Leeds it was found that beds taking septic effluent showed much higher capacities than those which received crude sewage. Similar conclusions were drawn by the experts at Manchester, although the experiments made with crude sewage were not exhaustive. The capacity of beds treating septic effluent decreased during the first three months and then remained fairly constant at about 33 per cent (of the original cubic contents), as shown in fig. 6. At Burnley, with septic effluent, the capacity of contact beds fell from 44 to 19 per cent; at Exeter it fell from 39 to 28 per cent, and at Leicester from 49 to 29 per cent. At Sutton a minimum of 21 per cent was reached (R. S. C., 1902 a). At Oldham "no clogging" was reported after two years (Oldham, 1901). In still other places even crude sewage has been treated with success. At West Bromwich the capacity of primary beds fell from 33 to 19 per cent and of secondary beds from 33 to 24 per cent in something over a year. At Newbury the capacity of single-contact beds of clinker fell from 19,000 to 10,000 gallons, and that of gravel beds from 19,000 to 9,000 gallons in a year's operation. At Hampton it is claimed that coarse beds after more than two years maintain "their original liquid capacity." At Maidstone and Wellington (Somerset) absence of sludge deposits in the beds was reported (R. S. C., 1902 b).

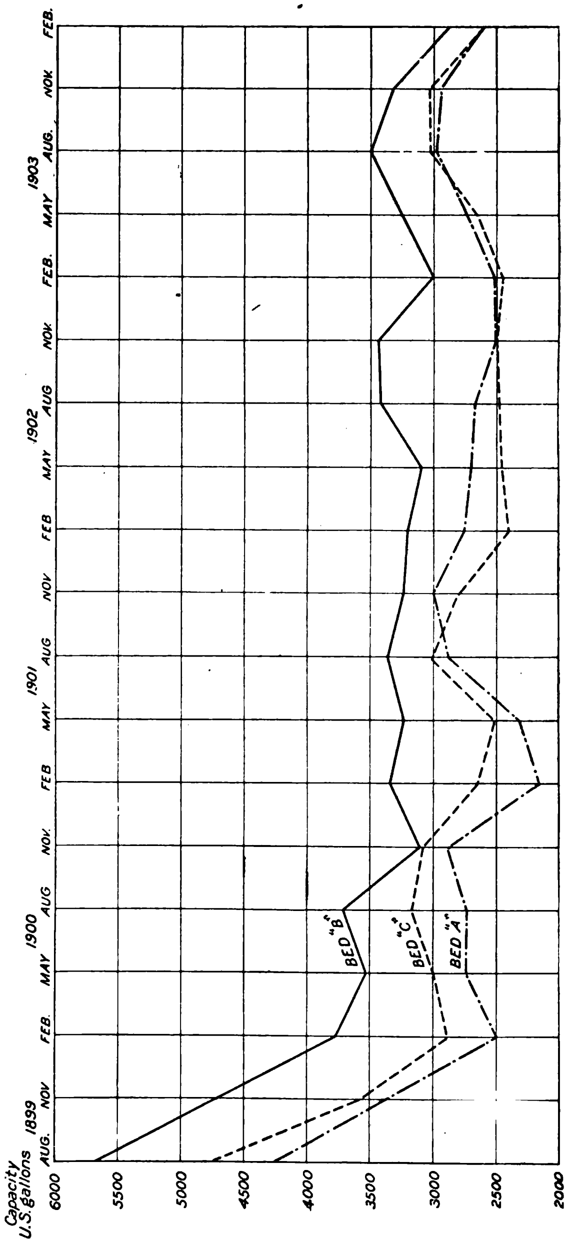

FIG. 6.—Loss in capacity of contact beds at Manchester, England

Experiments in Germany have shown less favorable results as to clogging, perhaps from the use of rather fine material and the treatment of very strong sewages. Dunbar's figures, as given in Table XXVIII, indicate final capacities of only 15 to 20 per cent with material ranging down to one-eighth and three-sixteenths inch. Experiments M, N, O, and P, with three-eighths to 1⅛ inch material, show results substantially like those obtained in England. German practice, however, tends to single contact in beds of fine material. Under such conditions it appeared at Hamburg that the loss in capacity went on in a pretty regular ratio to the amount of applied sewage, the beds soon being so clogged that their capacity fell to 15 or 20 per cent. The average reduction with different materials is shown in Table XXXII. Capacities were not satisfactorily restored by periods of rest.

TABLE XXXII.—*Reduction in capacity of Hamburg filters (Dunbar and Thumm, 1902).*

Material.	Loss in capacity (gallons per million gallons filtered).	Material.	Loss in capacity (gallons per million gallons filtered).
Single contact.		*Second contact.*	
Slag, ⅛- to 5/16-inch	1,330 1,680	Slag, ⅛- to 5/16-inch	420
		Gravel, ⅛- to 5/16-inch	700
Coke, ⅜- to 1⅛-inch	340	Coke, ⅛- to 5/16-inch	630
Gravel, ⅜- to 1⅛-inch	280	Slag, ⅜- to 1⅛-inch	340
Slag, ⅜- to 1⅛-inch	170	Coke, ⅜- to 1⅛-inch	360
Brick, ⅜- to 1⅛-inch	440	Gravel, ⅜- to 1⅛-inch	460
		Gravel and iron, ⅜- to 1⅛-inch	650

The German investigators accept this serious clogging with equanimity and suggest the removal and washing of the material when the capacity falls to 20 to 25 per cent. This would be required two or three times a year (Dunbar and Thumm, 1902). The Prussian commission at Berlin came to similar conclusions (Bruch, 1899). Material showed in these experiments a considerably greater capacity after washing than when it was first used. It seems probable that the use of coarser materials, which under proper conditions do not require so frequent removal, is a more economical process. Some of the English filters, for example, have been operated for six years with fair success (Martin, 1905).

Next to the nature and size of filling material the depth of the contact bed is the most important point of general theoretical interest in its construction. Exhaustive experiments were carried out on this point by Clowes and Houston (1904) at London, from which it appeared that beds 3 feet, 5 feet, and 13 feet in depth gave equally good effluents. Studies at Exeter, in which samples were taken from taps placed at different depths in a contact filter, showed the best results at 3 feet below the surface, and at Manchester a 15-inch bed gave specially good results. At Leeds, on the other hand, 6-foot beds proved better than those of half that depth (R. S. C., 1902 a). Thumm (1902) considers 4½ to 6 feet a maximum depth for one-third to 1 inch material and 1½ to 3 feet a maximum for material under one-eighth inch.

With regard to the operation of contact beds, the number of fillings is the first point to be considered. At Hamburg it was found that for single contact two fillings a day gave the best results, while for double contact six fillings of the primary beds and three fillings of the secondary beds were recommended (Dunbar and Thumm, 1902). In the Barking experiments (Clowes and Houston, 1904) it was shown that two fillings a day gave better results than one; apparently a single filling does not maintain the bacteria at their maximum effectiveness. Birmingham experiments have indicated three fillings a day as effective, to be cut down to two if specially high purification is desired (Watson, 1903). At Crossness it was found that London sewage could be purified with as many as four fillings. At Manchester (1901) also four fillings were recommended.

The distribution of fillings at regular intervals over the twenty-four hours does not appear to be a necessity. At Manchester contact beds were operated for two months with four even six-hour cycles and then for three months with four cycles in ten hours, followed by fourteen hours' rest. The results, as shown in Table XXXIII, were better by the second method.

TABLE XXXIII.—*Results of operation of contact beds at Manchester, England* (*R. S. C.*, *1902 b*).

Mode of operation.	Analyses of effluent (parts per million).			
	Oxygen consumed in 4 hours at 80° F.	Nitrogen as—		
		Free ammonia.	Albuminoid ammonia.	Nitrates.
4 cycles in 24 hours	29	16.8	1.5	2.6
4 cycles in 10 hours	22.3	14.8	1.1	6.3

The duration of the full period may also vary. Dibdin adopted two hours, and this is perhaps the general English practice. In Germany, too, Schumburg and others advocate this period (Bruch, 1899). Harding at Leeds found that one hour gave inferior results, while four hours was no better than two (R. S. C., 1902 a). Roscoe and Cameron, on the other hand, advocate shortening the period to one hour (R. S. C., 1902 a). Frankland found that a value for oxygen consumed of 555 parts per million for raw sewage was reduced to 93 in five minutes. It was still 93 after thirty minutes and 49 after twelve hours (Barwise, 1904).

The rate of filtration on contact beds, which is usually expressed in relation to the superficial area, is of course a function of the depth and the number of fillings. It would be more reasonable to measure contact rates in such units as acre-yards, which take account of depth. For uniformity with sand and trickling filters, however, the unit of superficial area is used in this paper. With a bed 3 feet deep and an open space of 33 per cent, which is a liberal estimate for a matured filter, two fillings a day would equal a rate of 0.65 million gallons per acre per day and three fillings a rate of about 1. In practice, necessary rests and loss of capacity being taken into account, three fillings of a 3-foot bed will not amount to a rate of more than 0.8. At Barking, in 1898, Clowes and Houston (1904) obtained with one filling rates of 0.6 for coke and 0.5 for ragstone, and in 1899 with two fillings the rates were increased only to 0.7. Watson (1903) considers 0.4 to 0.6 the best rate attainable, even when the sewage has been previously subjected to septic treatment. Table XXXIV, compiled from Watson's Birmingham lecture and from the testimony before the royal sewage commission, indicates the rates which have been recently obtained in actual operation or in experiment on a practical scale.

TABLE XXXIV.—*Contact-filter rates* (*Watson, 1903; Martin, 1905*).

Single contact.			Double contact.		
Place	Depth (feet).	Rate (million gallons per acre per day).	Place.	Depth (feet).	Rate (million gallons per acre per day).
Manchester	3.3	0.6	Burnley	3	0.3
Birmingham	4.5	.6	Leeds	5.5	.6
Croydon	3.7	.8	Blackburn	5.5	.8
Exeter	5	1	Sheffield	3.3	.8
Sutton	3.5	1	Carlisle	4	1.1
London	3	1.2	Sheffield	3.3	1.2
Leeds	4.5	1.4			

When a double-contact system is used the area must naturally be increased, generally by 50 per cent, the secondary beds being operated at double rate. The discussion of analytical results (pp. 70–71) shows that single contact rarely yields a stable effluent, while double contact usually does. The fact that, with a given area, better results can be obtained by double treatment at a certain rate than by single treatment at half that rate is made clear by some Manchester experiments, the results of which are given in Table XXXV.

TABLE XXXV.—*Results of double and single contact treatment at Manchester, England (Manchester, 1904 a).*

[Parts per million.]

	Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
	Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.	
Septic effluent	25.8	2.5	....	70
First contact	14.5	1.2	0.5	22
Second contact	4.1	.5	8.5	6.9
Septic effluent	31	3.5	....	80
Single contact (one-half rate)	13.3	1.3	4.3	16

In the Hamburg experiments it was found that with six daily fillings in the primary bed and three in the secondary bed as good results were obtained by double contact as with two fillings in single-contact beds. This is shown in Table XXVIII (p. 61), where experiment C and experiments L and D represent comparable conditions (Dunbar and Thumm, 1902). It may be noted in passing that in England general practice reverses this relation between primary and secondary beds. The Manchester commission suggested that secondary beds

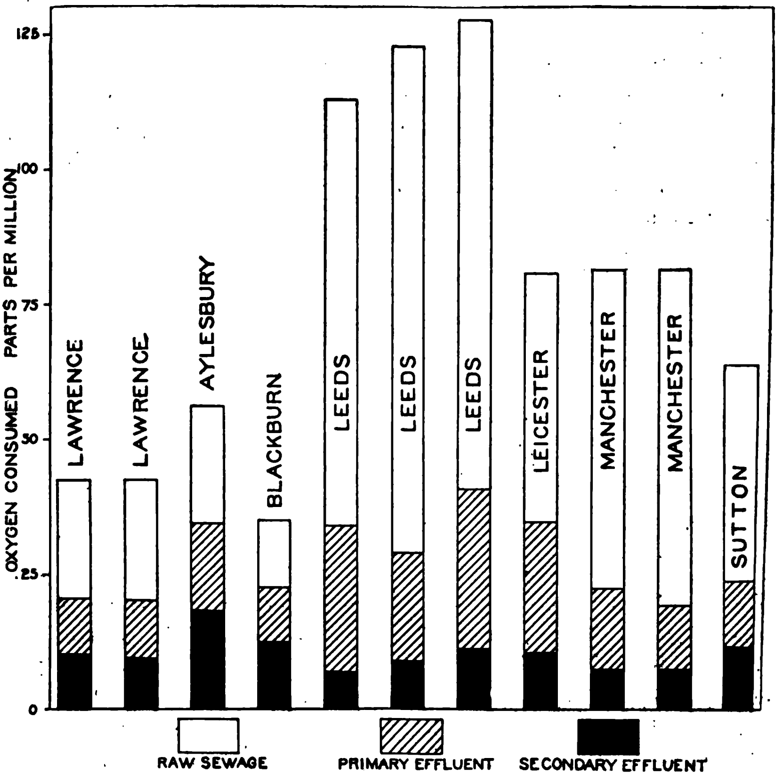

FIG. 7.—Comparison of sewages and effluents from contact beds.

should be operated at twice the rate of the primary beds (Manchester, 1900 a).

The purification effected by single and double contact filtration is fairly represented by the analyses, collected from various sources, given for comparison in Table XXXVI. The removal of oxygen consumed at the two stages in the process is plotted in fig. 7. It will be noted that the first contact removes somewhat more than half of the organic constituents of the sewage, as measured by oxygen consumed and albuminoid ammonia, and two-thirds or more of the suspended solids, while the second contact effects almost as great a purification on the first-contact effluent. Aylesbury and Blackburn showed the worst results among the English plants as far as ratio of purification is concerned. It will be noticed that these are the weakest sewages and in all sewage treatment the last fractions of organic matter are the most difficult to remove. Except at Lawrence the nitrate content of the effluent is rather low, notably at Leeds and Leicester.

TABLE XXXVI.—*Results of single- and double-contact treatment.*

[Parts per million.]

	Solids.						Nitrogen as—												Oxygen consumed in 4 hours at 80° F.[a]		
	Total.			Suspended.			Free ammonia.			Albuminoid ammonia.			Nitrites.			Nitrates.					
	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.	Sewage.	First contact.	Second contact.
Lawrence:[b]																					
Nos. 137-163	......	......	......	......	......	......	36.3	24.3	12	5.9	2.4	1.4	......	......	......	......	8.3	14.6	42.6	21.2	10.3
Nos. 137-164	......	......	......	......	......	......	36.3	24.2	8.6	5.9	2.4	1.2	......	......	......	......	8.3	21.7	42.6	20.4	9.4
Aylesbury[c]	1,190	1,020	920	367	112	0	56.4	42.7	23.6	6.5	4	1.9	......	0.3	0.9	......	.6	13.3	57.5	35.1	18.4
Blackburn[d]	1,080	602	596	474	60	3	23.3	17.3	11.4	2.8	1.7	1	......	.1	.2	......	.4	1.1	35.8	23	12.6
Leeds:[e]																					
Nos. 1 and 2	1,670	1,080	980	584	165	27	20.2	12.9	3.7	9.5	3.7	.9	......	......	......	......	......	5.6	115	36	7
Nos. 3 and 4	1,690	1,180	1,050	614	180	47	23.8	10.8	6.8	11.3	3.4	1.3	......	......	......	......	......	3.7	126	30	9
Nos. 5 and 6	1,780	1,170	1,020	661	196	47	24.1	14.5	7.8	11.8	4.7	1.7	......	......	......	......	......	1.8	132	42	11
Leicester[f]	1,320	1,070	1,020	296	73.2	23	......	......	......	10.6	4.2	2.5	......	......	......	0.6	.9	4.6	83.9	33.4	10.7
Manchester:[g]																					
Beds A and D	......	......	......	......	......	......	24	9.1	3.7	3.7	1.4	.6	......	.4	.2	......	5.6	10.6	83.9	23.1	7.5
Beds C and D	......	......	......	......	......	......	24	8.5	3.6	3.7	1.3	.6	......	.3	.2	......	6.3	10.8	83	19.6	7.5
Sutton[h]	1,630	895	1,000	824	45	5.6	94.2	32.6	8.3	7.3	2.9	1.4	......	1.5	.7	......	4.1	19.7	56.9	21.9	9.2

[a] At Lawrence, 2 minutes' boiling.

[b] Lawrence: No. 137-163, run for 18 months during 1901-1902; area of beds, 1/20000 acre each; first contact, broken stone ½ to 1 inch, taking raw sewage, rate 0.9; secondary bed, fine coke, rate 0.7 (Fuller, 1905). No. 137-164, run for 6 months during 1901; like No. 137-163, except that coke was "considerably finer" in secondary bed (Fuller, 1905).

[c] Aylesbury: Experiments during first 6 months of 1898; weekly analyses; no further data given (R. S. C., 1902 a).

[d] Blackburn: No further data (R. S. C., 1902 a).

[e] Leeds: Nos. 1 and 2, experiments during October, 1898, to October, 1899; beds about ⅛ acre in area; primary contains 5 feet of coke over 3 inches in diameter, receives raw or settled sewage at rate of 0.8; secondary, 6 feet coke, 3/16 to 1½ inches, rate like primary. Nos. 3 and 4, experiments during November, 1898, to June, 1900: beds each about ⅛ acre in area and 3 feet deep; primary bed filled with clinker ½ to 1 inch, and secondary 1/16 to ½ inch; rate during first 6 months, 1.1 (settled sewage), and during remainder of period 0.3 (raw sewage). Nos. 5 and 6, experiments during March to November, 1899; beds each ⅛ acre in area; primary bed, 3 feet of clinker, 1 to 2 inches; secondary bed, 3 feet of clinker, 1/16 to ½ inch; rate, 0.8, raw sewage on each bed; 4 hours' contact during a portion of the time (Leeds, 1900).

[f] Leicester: Process No. 14; experiments during November, 1898, to July, 1899; primary beds, 1/10 acre in area, filled with clinker 1¼ to 2¼ inches, 4½ feet deep; secondary bed, 1/20 acre in area, filled with 3 feet of clinker, ⅛ to ½ inch; rate, 1.6 on each bed, septic sewage (Leicester, 1900).

[g] Manchester: Experiments during January 4, 1900, to March 27, 1901; A and C were primary beds, the combined effluents of which were run on to D; area of each bed, 1/16 acre on the surface; slope inward, 2:1. A contains 3 feet of clinker ⅛ to ¾ inch; septic sewage at rate of 0.3. C contains 3 feet of clinker ¼ to ¾ inch; septic sewage at rate of 0.4. D contains 3 feet of clinker ⅛ to ½ inch; rate, 0.7 (Manchester, 1901).

[h] Sutton: Experiments from October, 1897, to August, 1898; coarse bed 3 feet deep, of burnt ballast; 5 beds of burnt clay; rate in each bed, 1 (R. S. C., 1902 a).

To these results may be added one more set of analyses to show what contact beds have actually accomplished in practical operation on a large scale. At Manchester, in 1903, 28 half-acre primary beds had been installed. They were 40 inches deep and filled with one-eighth to 1 inch clinker and were dosed with septic effluent. The results of the first year of operation are shown in Table XXXVII.

TABLE XXXVII.—*Efficiency of primary-contact beds at Manchester, England* (*Bredtschneider and Thumm, 1904*).

Date.	Rate (million gallons per acre per day).	Analyses (parts per million).					
		Oxygen consumed in 4 hours at 80° F.		Nitrogen as—			
				Free ammonia.		Albuminoid ammonia.	
		Septic effluent.	Contact effluent.	Septic effluent.	Contact effluent.	Septic effluent.	Contact effluent.
1902.							
January to March	0.46	...	...	...	...	...	...
April to June	.54	85	34	30	19	4	2.1
July to September	.56	80	32	29	17	3.2	1.7
October to December	.56	89	32	29	16	4	1.6

The effluent of the first contact process, as is obvious from the analyses in Table XXXVI, almost always retains too much organic matter to be considered satisfactorily purified. Two successive treatments, on the other hand, may produce an effluent which is nonputrescible and of good enough quality to be discharged into a stream. If still better results are desired a third contact may be made. Table XXXVIII shows what may be expected from such a method. The improvement in successive treatments progressively lessens, so that the results obtained are scarcely commensurate with the cost. The head required for successive contacts also introduces a serious factor.

TABLE XXXVIII.—*Results of triple-contact treatment.*

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
	Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Eastry (R. S. C., 1902b).						
Sewage	1,550	1,070	25.5	12.8	4.6	123
Bed 1	1,460	107	22	3	1.9	50.5
Bed 2	1,340	85.5	12.4	2.4	2.1	25.4
Bed 3	1,360	21.4	4.8	1.2	7.4	17.2
Leeds (Leeds, 1900).						
Sewage	1,760	632	27.6	12.4	...	127
Bed 1	1,250	274	18.6	7.1	...	62.4
Bed 2	1,060	113	13.5	5.1	...	39.6
Bed 3	1,030	110	9.7	3.5	2	27.5

It has been shown that the contact bed was developed from the intermittent sand filter with no idea of changing any other condition than the rate of operation. It was assumed that the chemical changes were the same in each case. Many English discussions of the process are based on this assumption, and Clark states that at Lawrence the process of nitrification is considered an essential for good purification (Clark, 1903).

Dunbar and Thumm (1902), in a beautiful series of experiments at Hamburg, have shown, however, that the reactions in the contact filter, as a result of the alternate aerobic and anaerobic conditions, follow a peculiar and characteristic course. First, during the reduction phase the solids in the sewage settle on the surface of the filling material and the soluble constituents are to a large extent absorbed by the bacterial jelly with which the material is clothed. This latter phenomenon takes place in virtue of the general tendency exhibited by colloidal films to remove substances from contiguous solutions (Phelps and Farrell, 1905). Dibdin illustrates the removal of suspended matter by analogy with the adhesion of floating chips to larger bodies, and compares the adsorption of dissolved material to the removal of lead acetate by passage through a carbon filter (Dibdin, 1904). The real purification of the adsorbed material has been shown by Dunbar (1905) to be a bacterial process, although Bredtschneider (1905) attempts to maintain its purely mechanical character. During the oxidation phase of full aeration the bacteria set up the ordinary oxidation processes of the intermittent filter, which may be indicated by the following generalized formula:

Reaction 1. Nitrification:

$$\text{(a) } 2R.N:R' + 3O_2 = R.O.R + 2R':O + N_2O_3;)$$

$$\text{(b) } N_2O_3 + O_2 = N_2O_5)$$

At the end of this period considerable quantities of nitrates are present in the filling material of the contact bed, as shown by Dunbar and Thumm (1902). Experiments by Phelps and Farrell (1905) indicate that the amount of nitrates increases with the length of the period. When the bed is refilled for the next cycle the same action continues for a time. Soon, however, the supply of dissolved oxygen is consumed, active nitrification stops, and anaerobic putrefactions begin, causing hydrolytic splittings of the following type:

Reaction 2. Hydrolysis:

$$(R.N:R' + 2H_2O = R.OH + HO.R'.NH_2)$$

At this stage the contact filter has the liquefying properties of the septic tank. There is a bacterial reduction of the nitrates to nitrites, and a formation of partly reduced nitrogenous bodies, primary amines, etc. This leads to a decomposition of the nitrites present and the liberation of gaseous nitrogen according to the following formula:

Reaction 3. Denitrification:

$$2HO.R'.NH_2 + N_2O_3 = 2R'(OH)_2 + 2N_2 + H_2O$$

During the reducing phase the nitrates formed in the empty period are partly or wholly removed. Much of the organic nitrogen originally present is lost as free nitrogen. Clark (1903) has pointed out that this loss amounts to from 38 to 50 per cent and Phelps and Farrell (1905) found a loss of from 35 to 50 per cent. The nitrates found in the final effluent give no true measure of the purification effected, since under ideal conditions the nitrates formed from half the nitrogen would be exactly used up in decomposing the other half. Dunbar and Thumm (1902) found that the highest purification frequently accompanied the lowest nitrate content in the effluent.

The process in the contact bed is evidently an extremely complex one, involving an alternation of anaerobic and aerobic processes. To those who, like most English authorities, believe that putrefaction is an integral part of all sewage purification, such a method must commend itself. Clark (1900) describes a suggestive experiment in which gravel filters were run at a rate of 0.5 with forced upward aeration. Comparing these filters with others operated on the contact plan, he finds that the latter operate for longer periods and at higher rates without clogging and produce better effluents. Nevertheless, in view of recent English work on open filters through which raw sewage is allowed to trickle continuously, and in the light of some of the writers' own experiments, it can not be conceded that the universal necessity for anaerobic treatment has been clearly proved. Even if the need for some such process be granted, its combination with aerobic action in the same filter must be regarded as of doubtful expediency. As Rideal says, "In methods involving a 'resting-full' and 'resting-empty period' there is alternate inversion of bacterial action between aerobes and anaerobes, with a disturbance of both." And again, "In ordinary bacteria beds these reactions are somewhat fortuitously reversed and confused, according to the periods of filling or rest, the fault being caused by mixing all the different bacteria in one or two large filters" (R. S. C., 1902 a). Chemically the decomposition of organic matter into free nitrogen which takes place in the contact bed seems quite ideal. Bacteriologically the combination of two diverse processes must be regarded as theoretically unsound.

Whatever may be thought of the principle of the process, its practical applicability under certain conditions has been thoroughly demonstrated. The results obtained with the famous 1-acre coke bed at Barking and with the double-contact system at Sutton have been amply confirmed. The Barking bed between 1894 and 1901, inclusive, purified 1,500 million gallons of sewage at an average rate of 0.5 for the whole period. The elaborate experiments at Manchester and Leeds showed that even strong industrial wastes could be treated on this principle. At Exeter, Yeovil, Barrhead, Oldham, and Burnley contact beds are being regularly operated with success.

That the double-contact process may yield effluents as good as those obtained from sewage farms in actual operation is indicated in Table XXXIX, which presents data obtained by two river conservancy boards in the examination of a number of plants. No distinction has been made as to methods of preliminary treatment. All the contact beds and most of the land areas receive septic or chemical effluent. The Mersey and Irwell standard is 1.4 parts per million of albuminoid ammonia and 14 parts of oxygen consumed. The Ribble standard is 1 part of albuminoid ammonia and 20 parts of oxygen consumed.

TABLE XXXIX.—*Comparison of contact treatment with irrigation and sand filtration, Mersey and Irwell and Ribble watersheds* (*R. S. C., 1902 b*).

District.	Disposal on—	Number of samples.		Per cent of samples below standard.
		Above standard.	Below standard.	
Mersey and Irwell	Contact beds	8	22	73
	Land	55	178	76
Ribble	Contact beds	16	22	58
	Land	88	207	70

German investigations have similarly shown at Hamburg (Dunbar and Thumm, 1902), at Berlin (Bruch, 1899), at Stuttgart (Schury, 1905), and elsewhere that a clear nonputrescible effluent may be obtained by the contact method.

Whether preliminary septic treatment is necessary before contact filtration must be decided by local conditions in the individual case. English opinion strongly inclines to the view that it is generally advisable. The consensus of evidence given before the royal sewage commission indicated that "crude sewage causes so serious a loss of capacity in contact beds as to require preliminary sedimentation and generally septic treatment as well" and that the use of the septic tank "greatly assists the life of the beds by preventing their becoming choked by the accumulation of mineral and indigestible fibrous matters" (Dibdin, 1903). The Leeds experiments certainly showed that the crude sewage of that city could not be treated successfully. At London, Birmingham, and Manchester the conclusion has been reached that septic treatment is desirable. It must be remembered that sludge is produced in the septic tank, the disposal of which must be balanced against the renewal of contact beds. The cleaning of contact beds is of course much more difficult than the emptying of a septic tank. On the other hand, the sludge produced in the beds is probably less in amount and of a less offensive character than that which accumulates in the tank. Furthermore, it has been suggested that septic treatment under certain conditions may interfere with the course of the later biological process. At Hamburg it was found that while contact beds could handle six doses a day of raw sewage only two doses of septic effluent could be applied, a third dose producing a dark and malodorous effluent (Dunbar and Thumm, 1902). Chemical treatment also interfered with the process, as shown in Table XL.

TABLE XL.—*Results of contact treatment of crude sewage and chemical effluent (Dunbar and Thumm, 1902).*

Precipitant.	Oxygen consumed in 10 minutes' boiling (parts per million).	
	Applied liquid.	Contact effluent.
None	102	27
Lime	69	51
Lime and iron	69	53
Iron	72	19

PURIFICATION OF SEWAGES BY A CONTINUOUS TRICKLING PROCESS OVER COARSE MATERIAL.

At about the same time that the system of contact treatment was worked out the foundations were laid for the development of another method of purification by rapid filtration through coarse material under wholly aerobic conditions. In modern filters of this type the supply of oxygen is maintained and the flow slackened sufficiently to permit purification by applying the sewage in a fine, continuous spray, and the beds are termed sprinkling or trickling filters. The early Lawrence experiments on the filtration of sewage "through clean gravelstones larger than robins' eggs" (Mills, 1890) furnished the first suggestion of such a process. In 1892 Hazen started a filter of one-fifth-inch material which received four doses of sewage a day and was artificially aerated. The rate was increased from 0.14 at the start to 0.48. The surface clogged badly, but the effluent was good, showing 30 parts per million of nitrates. In 1892 Lowcock, at Malvern, England, constructed a gravel filter with a sand layer on its surface and filtered chemical effluent at a rate of nearly 0.3 million gallons per acre per day, forcing air under pressure into the middle layer of the bed. A good effluent was obtained and the filter was operated for fifty-one days without rest (Lowcock, 1894). Similar filters were later constructed at Wolverhampton and at Tipton (Rideal, 1901). At both places ordinary trickling filters have since been installed (R. S. C., 1902 a). In the United States Waring was attempting at the same time to use the principle of forced aeration. He obtained a patent on his process as early as 1891 and carried out a series of experiments at Newport in 1894 on "the mechanical straining out of all solid matters carried in suspension in sewage and their subsequent destruction by forced aeration and the purification of the clarified sewage by bacterial oxidation of its dissolved organic matter in an artificially aerated filter." Straining through broken stone removed 40 per cent of the nitrogenous matter in the sewage, and it was concluded that "if the thick sludge is removed and the upper 6 inches of the filtering bed opened up by raking or plowing after the filter is drained an aeration period not exceeding five days is sufficient to quite restore the strainer to its original efficiency." Waring says further that "the sewage, instead of passing through the filter in a solid column, as in the former case, trickles down in a thin film over the surfaces of the particles of coke or other filtering material, while through the voids between the particles and in immediate contact with the trickling films of liquid a current of air is constantly rising, being introduced at the bottom of the tank by a blower." It is stated in the report of these experiments that the aerators removed "over 95 per cent of the organic nitrogen of a strainer effluent applied at a rate of at least 800,000 gallons per acre per day" (Waring, 1895).

Waring's principle of oxidation was undoubtedly correct; but the method of forced aeration is of more doubtful expediency. For the complete oxidation of various organic compounds Dibdin (1903) calculates that an amount of oxygen equal to from two to four times the weight of their total carbon would be required. This means with an average sewage a supply of 5 to 10 liters of air to a liter of sewage. The difficulty of maintaining such a supply of air by forced aeration is manifest, and the plants actually installed on the Waring plan have not generally operated with marked success. The best example of the process is that at East Cleveland. Here the beds speedily clogged when treating raw sewage, although since the installation of a septic tank for preliminary treatment they have worked better. The engineer of the Ohio State board of health says of this plant: "When visited in winter the surfaces of the aerators were frozen and they were out of service, the sewage being passed through septic tanks and primary and secondary filters only. It is said to be practically impossible to clean the surface of the aerators during cold weather, but on account of the rapid rate of filtration these filters rapidly accumulate solid matter on their surfaces and need frequent cleaning" (Pratt, 1905).

A practically successful solution of the problem of aeration has been reached along another line, and depends on the supply of sewage, continuously or at very frequent intervals, in small amounts distributed evenly over the whole area of a filter. Under such conditions the sewage trickles in thin films over the surface of the filling material, while the spaces between are continually filled with air, the oxygen content of which in practice does not become seriously exhausted (R. S. C., 1902 a). The air supply under the best conditions may amount to five times the volume of sewage. The material over which films of sewage continuously trickle supports an active growth of micro-organisms. The condition is analogous to the cultivation of acetic-acid bacteria in the process of vinegar manufacture by the flow of alcoholic liquor over shavings. The complications introduced by "a series of compensating errors of surfeiting and starvation" are exchanged for a simple and constant condition. Under the name of the trickling filter, the percolating filter, the "intermittent continuous" filter, the sprinkling filter, etc., this process has come nearer than any other to realizing the ideal conditions for rapid purification.

The first description of a method for sewage treatment based on the plan of trickling over coarse material with natural aeration was published by Stoddart in 1893. In the next year the same investigator exhibited a model at the Bristol meeting of the British Medical Association in which sewage and other liquids were discharged in drops over a filter of coarse chalk. A solution of ammonium sulphate containing 140 parts per million of nitrogen was almost perfectly nitrified at a rate of 11.6 million gallons per acre per day. Sewage was completely nitrified at a rate of 1.2 and well purified at 5.8 (Dibdin, 1903). Nitrification was found to increase with the depth of the filter. The first working filter actually constructed by Stoddart was installed at Horfield in 1899. Its efficiency under various conditions of flow is indicated in Table XLI.

TABLE XLI.—*Results of purification by Stoddart trickling filter at Horfield, England* (*R. S. C.*, *1902 a*).

Conditions.	Rate (million gallons per acre per day).	Material.	Analyses (parts per million).				
			Nitrogen as—			Oxygen consumed in 4 hours at 80° F.	Suspended solids.
			Free ammonia.	Albuminoid ammonia.	Nitrates and nitrites.		
Exceptionally strong sewage.	3.4	Sewage	426	113	0	330	....
		Septic effluent	119	9.1	0	50	....
		Trickling effluent	74.2	3.1	21.4	21	....
Dry-weather flow	8.2	Sewage	80.5	10.7	0	77	300
		Septic effluent	31.8	3.8	0	17.4	45.6
		Trickling effluent	15.2	1.1	25.7	7	0
Wet-weather flow	10.5	do	1.6	.4	18.1	....	0

The same principle was independently worked out by Corbett, the borough engineer of Salford, in a series of experiments begun in 1893 under the inspiration of the work of the Massachusetts State board of health. He first used wooden troughs for distribution and later fixed sprinklers, obtaining excellent results in the latter case. Ducat, another pioneer in the development of the trickling filter, urged the importance of thorough aeration, building filters with open sides to attain that end, and maintained that the aerobic process alone was entirely competent for the treatment of crude sewage. He installed a small filter at Hendon in 1897.

Finally, in connection with the development of this process, should be mentioned Scott-Moncrieff, who carried its principles to a logical extreme in a series of experiments at Ashtead in 1898. He believed that several different types of organisms were concerned in the purifying process and that their separate and successive cultivation under perfect aerobic conditions would give the most favorable results. He therefore constructed a series of nine trays of 1-inch coke, each 2 by 7 feet by 7 inches deep, arranged one over the other, with a space of 2 inches between each pair. The effluent from a "cultivation tank" was discharged on the upper tray by a tipping bucket at a rate of 1.3 million gallons per acre per day (0.14 on the whole area of nine trays), and its passage through the series occupied from eight to ten minutes. The degree of purification attained, as indicated in Table XLII, was extraordinarily high.

TABLE XLII.—*Results of trickling filtration through Scott-Moncrieff's trays (Scott-Moncrieff, 1899).*

[Parts per million.]

Effluents of—	Nitrogen as—				Oxygen consumed in 4 hours at 80° F.
	Free ammonia.	Albuminoid ammonia.	Nitrites.	Nitrates.	
Cultivation tank	103	12.3	0	1.2	98.4
First tray	86.5	10.3	9.9	1	66.9
Second tray	74.2	8.2	9	4.8	57.7
Third tray	41.2	4.9	7.8	18.7	44.9
Fourth tray	33	2.9	6.6	27.6	17.3
Fifth tray	12.4	1.2	4.8	46.8	12.8
Sixth tray	14.4	2.9	5.1	44.2	15
Seventh tray	2.9	2.5	0	66	7.6
Eighth tray	1.7	5.3	0	73.2	4
Ninth tray	2.1	4.9	Slight tr.	90	5.9

A plant of this type has been installed at Caterham Barracks, where it handles daily 16,000 gallons of very strong sewage at a rate of 0.4. Oxygen consumed is reduced from 92 to 27 parts per million, free ammonia from 149 to 50 parts, and organic nitrogen from 27 to 7 parts, with a formation of 90 parts of nitric nitrogen (Rideal, 1901). The German commission on its visit to England in 1902 reported that the effluent from this plant was stable, although it contained 68 parts per million of nitrogen as free ammonia, 5.8 parts of organic nitrogen, and 51 parts of oxygen consumed (Bredtschneider and Thumm, 1904).

It is not clear that there is any such complex division of labor between various classes of nitrifiers as Scott-Moncrieff postulates. Whether any important advantage is to be gained by dividing a trickling filter into layers with air spaces between has never been definitely determined. At Salford Corbett found no gain from dividing his filters into three or four successive heights of 20 inches each (Rideal, 1901).

The general practice is to construct trickling filters in single beds, which are merely heaps of the selected filtering material. It is not necessary that such a filter should be tight as long as its bottom is built with sufficient slope to carry off the effluent. It is desirable that it should be underdrained in some way in order to avoid clogging and to maintain a good air supply, passing upward, chimney fashion, through the filter. In some cases tile drains are so arranged as to form practically a false floor. The walls of the Ducat filter are built of open drain pipe inclined upward and connected with aerating drains at intervals in the body of the bed. The Whittaker-Bryant filters at Accrington and elsewhere are octagonal in shape, with walls of open brick and central open-brickwork aerating wells. Both these types are costly (Kinnicutt, 1902). Filters may be constructed more simply by merely surrounding the filtering material with a fence of upright palings. The Stoddart filter is a heap of coke or cinders of this sort on a sloping floor without any walls. The two quarter-acre trickling beds now in operation at Birmingham are essentially of this type (Watson, 1903). The oldest of these beds was built of slag graded upward from one-half inch to three-fourths inch, heaped up without underdrains, the outside being held together by iron bands. More recent filters are of one-half to 3 inch broken brick underdrained by a false floor of tiles.

The most difficult point in the construction and operation of the trickling filter is the distribution of the sewage over its surface. The ideal condition for aeration would be the discharge of sewage in a fine and even spray over the whole surface of the filter. On the other hand, there is some evidence that a too regular distribution favors alien growths, which clog the surface of the filter. Scott-Moncrieff and Ducat originally used tipping buckets and troughs placed at intervals over the filter, relying on the dash to distribute over intermediate areas. This plan has been tried at Hendon and Leeds. At the other extreme in principle is the Stoddart distributer as used at Horfield. It is practically a series of channels, over the sides of which the sewage overflows continuously, dripping from a series of points on the under side, 360 points being allowed to a square yard. Theoretically this should secure a very even distribution; but such channels are liable to buckle and it is difficult to keep them level. Furthermore, they are liable to clogging from fungous growth (Barwise, 1904). A more practical method than either the tipping bucket or the Stoddart drip distributor is the method of distribution under pressure through perforated pipes. This was developed at Salford after various other attempts with troughs and with a thin layer of sand laid over the surface of the main filter. Disk-like caps were placed over the openings of the pipes in some early experiments in order to secure a good spray for distribution. Then the attempt was made to get a spray by the impact of two converging flows, and finally a special form of opening was designed to give a rotating movement to the stream. This system is in use on the new filters at Birmingham and works well when good pressure is available (Baker, 1904). Barwise (R. S. C., 1902 a) describes the use in Derbyshire of fixed perforated pipes with metal disks placed over the outlets for spraying, dosed intermittently by automatic flush tanks. The same principle is used at Chesterfield. At Accrington intermittently operated fixed sprinkler pipes gave poor results in some preliminary experiments (Bredtschneider and Thumm, 1904).

Many plants in England are equipped with still more complex revolving sprinklers operated either by the pressure of their own jets or by mechanical power. The Candy-Whittaker sprinklers at Accrington are of the former type. With this filter, as well as with that of Ducat at Leeds, it was thought that it would be of advantage to warm the sewage before applying it, and the temperature was raised about 4° by the steam of the pulsometer used for pumping. The heating seems of little advantage, and at Leeds was found actually harmful, since it promoted surface growths which tended to clog the filter. All revolving sprinklers require much attention to keep them in operation and are subject to grave derangement from weather conditions. Daily cleaning with brushes is necessary with many plants to prevent serious clogging of the openings. Even more elaborate than the ordinary revolving sprinklers is the Scott-Moncrieff distributor installed at Birmingham, in which a radial trough revolves about an axis at the center of the bed, its outer end resting on a moving wheel, sewage running in a thin film over a weir which extends for the length of the trough.

With regard to depth and material in trickling filters there may be considerable latitude. In a series of experiments at Salford, analyses from which are quoted in Table XLIII, no better results were obtained with an 8-foot filter than with one only 5 feet deep.

TABLE XLIII.—*Efficiency of trickling filters of different depths at Salford, England (Bredtschneider and Thumm, 1904).*

[Parts per million.]

	Suspended solids.	Oxygen consumed in 4 hours at 80° F.	Nitrogen as—	
			Free ammonia.	Albuminoid ammonia.
Raw sewage	280	58	19.8	5.1
Chemical effluent	40	42	16.5	4.5
Roughing filter	20	40	16.5	4.3
Trickling filter effluent (5-foot)	0	6.5	5.3	2.1
Trickling filter effluent (8-foot)	0	5.5	4.9	1.6

Bell testified in 1902, apparently with regard to the same filters, that the oxygen-consumed value for the 8-foot filter was 12, against

15 for the 5-foot bed. He considered this difference too little to pay for the increased depth (R. S. C., 1902 a). Whittaker, on the other hand, reports much better results with beds 9 feet deep than with a depth of 4 feet 8 inches (R. S. C., 1902 a). Probably 4 feet is the safest minimum, and greater depths are desirable because of the danger in shallow filters that streams of unputrified sewage may pass through channels, due to irregular packing of the material. Ducat recommended a depth of 5 feet when the effluent was to be discharged into brackish water, 8 feet for discharge into rivers, and 10 feet for small streams. The period of flow through trickling beds varies, at Leeds, from two or three minutes with very coarse beds up to thirty minutes with fine material.

It is probable that there is a maximum amount of organic matter present in sewage which can be easily nitrified by the trickling process, and that additional action does not produce results commensurate with the cost of deep single filters or of double and triple beds. Thus at Leeds it was found that the rate of improvement in the effluent of three successive beds rapidly decreased, as shown in Table XLIV.

TABLE XLIV.—*Efficiency of trickling filters at Leeds, England (Dibdin, 1903).*

[Parts per million.]

	Total solids.	Suspended solids.	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
			Free ammonia.	Albuminoid ammonia.	
Sewage	1,760	631	27.6	12.2	127
Effluent No. 1	1,250	275	18.5	7	62.5
Effluent No. 2	1,060	113	13.3	5	39.6
Effluent No. 3	1,010	110	9.7	3.5	27.6

With regard to the best material for the construction of trickling filters, data have been collected in a number of the English experiments. At Salford slag was found somewhat better than polarite, gravel, coke, or clay (Bredtschneider and Thumm, 1904). At York a well-controlled series of investigations indicated, as shown in Table XLV, that coke and boiler slag (clinker) are slightly better than brick and blast-furnace slag.

TABLE XLV.—*Efficiency of trickling filters of different material at York, England (Bredtschneider and Thumm, 1904).*

[Parts per million.]

	Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
	Albuminoid ammonia.	Nitrates.	
Raw sewage	13.9	0	82.9
Broken-brick effluent	1.4	18.4	10
Blast-furnace slag effluent	1.2	18.8	9.6
Coke effluent	.9	23	7.1
Boiler-slag (clinker) effluent	1	22	6.9

Coal has been found especially favorable to the process. At Buxton the effluents from destructor breeze and coke showed, respectively, 0.8 and 0.9 parts per million of albuminoid ammonia and 0.8 and 0.7 parts of nitrates, while a coal filter yielded only 0.4 part of albuminoid ammonia and 3.4 parts of nitrates (Barwise, 1904). Striking differences obtained at Tipton are shown in Table XLVI.

Table XLVI.—*Efficiency of trickling filters of various types at Tipton, England (Barwise, 1904).*

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
	In solution.	In suspension.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Tank effluent	827	16	10.3	1.9	0	7.7
Coke-breeze effluent	840	9	7.4	1.3	3.8	5.8
Lowcock's filter effluent	807	14	2.2	.4	7.4	2.2
Garfield's coal-filter effluent	914	3	1.6	.3	8.1	2

On the whole, it seems probable that any hard, smooth material will serve well for the trickling filter. Coal is perhaps most promising, but granite, flints, gravel, and hard clinker are all suitable.

The size of material used may also be varied considerably within certain limits. The elaborate experiments carried out by Reid at Hanley, cited in Table XLVII, indicated that fragments from three-sixteenths inch up to 1½ inches yielded almost identical results (Hanley, 1904). Barwise (1904) suggests one-eighth to one-half inch material. Among the witnesses before the royal sewage commission Garfield recommended one-sixteenth to three-sixteenths inch, Ducat one-eighth to one-half inch, Corbett three-sixteenths to three-fourths inch, Candy three-sixteenths to one-half inch for fine and three-fourths inch to 3 inches for coarse beds, Harding one-fourth inch to 1½ inches for fine and over 3 inches for coarse beds, Whittaker 1 inch to 1½ inches, and Stoddart 2 to 3 inches.

Table XLVII.—*Efficiency of trickling filters with material of various sizes at Hanley, England (Hanley, 1904; Wilcox and Reid, 1904).*

	Size of material. (inches).	Analyses (parts per million).					
		Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
		Dissolved.	Suspended.	Free ammonia.	Organic.	Nitrates.	
Sewage	....	1,250	629	17.3	6.3	0	38.5
Septic tank	....	1,050	44	15	2.2	0	17.3
Rectangular bed:							
Section 1	$\frac{3}{16}$ to $\frac{1}{8}$	1,120	4	.7	.2	17.5	2.7
Section 2	$\frac{1}{2}$ to $\frac{1}{8}$	1,120	3	.8	.3	17.3	2.8
Circular bed:							
Section 1	$\frac{3}{16}$ to $\frac{1}{8}$	1,120	2	.8	.2	16.6	2.4
Section 2	$\frac{1}{2}$ to $\frac{1}{8}$	1,130	14	.3	.2	15.3	2.6
Section 3	$\frac{1}{2}$ to $\frac{1}{4}$	1,130	7	.3	.2	16.2	2.5
Section 4	$1\frac{1}{2}$ to $\frac{1}{2}$	1,130	17	1	.4	16.2	3.3

The rate at which trickling filters may be operated seems generally to lie between 1 and 3 million gallons per acre per day. Ducat and

Scott-Moncrieff recommend a rate of 1.2; Barwise suggests 1.5; Watson gives the figures quoted in Table XLVIII for current English practice. Still higher figures may be attained at times. At Salford the rate, at first 3, was raised to 6 without injuring the quality of the effluent (Bredtschneider and Thumm, 1904).

TABLE XLVIII.—*Depth and rates of trickling filters* (*Watson, 1903*).

Place.	Depth (feet).	Rate (million gallons per acre per day).
Leeds	9	1.2
Accrington	8.5	2.3
Birmingham	5	1.2
Hyde	9	2.6
York	6.5	2.6
Rochdale	9	2.3

The analytical results produced by a number of English trickling filters are brought together in Table XLIX. It will be noticed that the process here is a true nitrification, producing considerable amounts of nitrate in the effluent. The purification is good, distinctly higher in general than that obtained by the double-contact process. The results as measured by oxygen consumed are plotted in fig. 8. The trickling effluents are in general better than those yielded by contact beds or sewage farms, if not quite equal to those produced in intermittent filtration.

TABLE XLIX.—*Efficiency of trickling filtration.*

[Parts per million.]

Place.	Material.	Solids.		Nitrogen as—				Oxygen consumed in 4 hours at 80° F.
		Total.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites and nitrates.	
Accrington[a]	Sewage	....	....	....	4.6	....	0	49.9
	Effluent	....	....	....	1.5	....	23.3	18.1
Hendon[b]	Sewage	....	....	71.6	13.2	....	....	147
	Effluent	....	....	2.5	.8	....	4.8	7.8
Hyde	Sewage	....	....	39.5	16.5	....	....	14
	Effluent	....	....	5.1	1.6	12	13.7	16.3
Leeds[c]	Sewage	1,120	187	21.2	5.1	....	....	57.5
	Effluent	1,000	80	8.1	[d] 1.3	7.8	....	[d] 9.8
Do.[e]	Sewage	1,110	229	21.7	5.4	....	....	59.7
	Effluent	1,010	110	6.2	[d] .9	9.6	....	[d] 8.4
Do.[f]	Sewage	1,850	768	33.9	12.8	....	....	114
	Effluent	1,020	0	11.7	1.4	4.5	....	[d] 10.1
Do.[g]	Sewage	1,820	850	32.8	12.6	....	....	141
	Effluent	986	Trace.	1.9	.5	12.1	....	[d] 3.4
Do.[h]	Sewage	1,470	486	23.5	9.4	....	....	116
	Effluent	979	81	3.2	1.3	6.2	....	12.1
Wolverhampton[i]	Sewage	....	....	47.1	3.3	1.4	....	43.3
	Effluent	....	....	23.8	.6	16.4	....	3.6
York[j]	Sewage	840	....	31.8	5.9	0	....	42
	Effluent	719	....	2.1	.6	113	....	6.6

[a] Thermal aerobic filter, September 19 to October 19, 1898, receiving septic effluent (Rideal, 1901).
[b] Ducat filter, October 14, 1898, receiving crude sewage; single analysis (Rideal, 1901).
[c] Whittaker bed No. 1, March 9, 1899, to May 8, 1900, receiving septic effluent (Martin, 1905).
[d] Analysis made of the rough settling of suspended solids.
[e] Whittaker bed No. 2, September 2, 1899, to January 30, 1900, receiving septic effluent (Martin, 1905).
[f] Ducat filter, March 29 to April 30, 1900, receiving crude sewage (Martin, 1905).
[g] Ducat filter, June 13 to July 7, 1900, receiving crude sewage (Martin, 1905).
[h] Leeds filter, December 13, 1900, to January 14, 1901, receiving crude sewage (Martin, 1905).
[i] Coal filter, January 1896, to September, 1898, receiving chemical effluent (R. S. C., 1902a).
[j] Septic effluent.

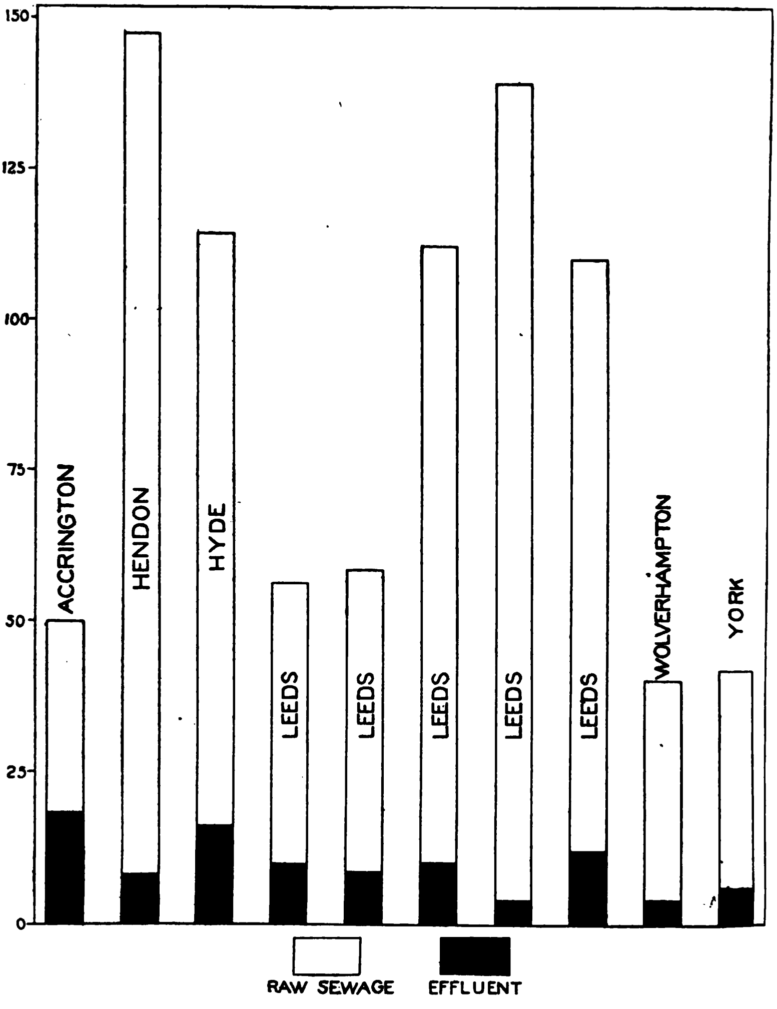

FIG. 8.—Comparison of sewages and effluents from trickling beds, showing oxygen consumed, in parts per million.

Barwise (1904) gives a number of analyses of effluents covering shorter periods, which are summarized in Table L.

TABLE L.—*Analyses of trickling-filter effluents (Barwise, 1904).*

Place.	Rate (million gallons per acre per day).	Analyses (parts per million).		
		Nitrogen as—		Oxygen consumed in 4 hours at 80° F.
		Albuminoid ammonia.	Nitrates.	
Chesterfield	0.5	0.6	19.3	....
Burton	.5	.4	8.7	....
Langwith	1	.2	4	0.3
Chesterfield Borough	1	.5	18	.1
Long Eaton	1	.7	6	.1
Buxton	1	.2	2.5	.1
Dronfield	1	.2	13	.7

The effluent of the trickling filter contains, as a rule, a certain amount of flocculent organic matter which mars its appearance, but this matter has been more or less completely oxidized and is of a stable, humus-like character. The effluents look worse and keep better than would be expected from their analyses. Clark has brought out this difference in a series of experiments summarized in Table LI. In each case the effluent was allowed to stand in a stoppered bottle in the laboratory, samples being withdrawn at intervals. To judge by free ammonia and oxygen consumed, both contact effluents were, at the start, better than those from the trickling filters. It was evident, however, that—

> The large amount of residual organic matter in the effluents of filters Nos. 135 and 136 had been, owing to the aerobic conditions prevailing in these filters, as evidenced by the high nitrates in the effluents, so changed by the bacteria and air that it was in a fairly stable condition. The effluents of these two filters—Nos. 135 and 136—contained dissolved oxygen; at the end of the period of experiment, notwithstanding the large amount of organic matter present, no putrefaction took place, odors did not develop, and the organic matter present remained practically without change. The effluents of filters Nos. 137 and 163 contained less organic matter than the effluents of filters Nos. 135 and 136, but were, nevertheless, in a much lower state of nitrification; dissolved oxygen either was not present or disappeared quickly, and putrefaction occurred. Instead of the amount of nitrogen present as free ammonia remaining constant, as in the effluents of filters Nos. 135 and 136, it increased. The amount of oxygen consumed, instead of decreasing, increased eventually in the effluent of filter No. 137, and the anaerobic actions in the bottles containing this effluent and the formation of gas were quite noticeable, odors developing also. [Clark, 1902.]

The suspended solids may be easily removed from the trickling effluent by a short sedimentation. When so separated they are sometimes in themselves putrescible (R. S. C., 1902 a), but usually show only a small proportion of unstable matter. At Leeds (1900) analyses of the dried sediment from a trickling-filter effluent showed the following composition: Organic matter, 31 per cent; mineral matter insoluble in acids, 19 per cent; other mineral matter, 19 per cent. The clear liquid and the suspension which comes fresh from the trickling filter are stable when the bed is operating properly.

TABLE LI.—*Comparative stability of stored effluents from contact and trickling filters* (*Clark, 1902*).

TRICKLING FILTER NO. 135.

Time elapsed (days).	Nitrogen as—					Oxygen consumed in 2 minutes' boiling, corrected for nitrites.	Oxygen dissolved (per cent of saturation).
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.		
		Total.	In solution.				
	Parts per million.						
0	20.1	2.3	1	51.8	0.1	24.4	34.3
7	18.2	2.2	.8	44.2	6	19.5	15.3
14	19.4	1.9	.7	49.1	1.1	20.9	9.9
21	19.4	2.1	.8	46.2	1.3	21.5	13.2
28	20.1	2	7	39.4	2	21.3	7.7

TABLE LI.—*Comparative stability of stored effluents from contact and trickling filters* (*Clark, 1902*)—Continued.

Time elapsed (days).	Nitrogen as—					Oxygen consumed in 2 minutes' boiling, corrected for nitrites.	Oxygen dissolved (per cent of saturation).
	Free ammonia.	Albuminoid ammonia.		Nitrates.	Nitrites.		
		Total.	In solution.				
	Parts per million.						
TRICKLING FILTER NO. 136.							
0	13.2	2.4	1.1	52.8	0.1	25.6	51.7
7	13.2	2.1	.7	50.8	1.1	19.4	15.5
14	13.2	1.9	.6	49.7	.5	18.3	5
21	13.2	1.8	.6	47.3	.2	17.1	1.6
28	13.5	1.9	.6	44	0	18.4	.3
CONTACT FILTER NO. 137.							
0	21.4	2	1.4	6.2	0.2	17.4	0
7	23.1	1.8	1.1	.1	0	22.8	0
14	23.9	1.6	.8	.1	0	24.8	0
21	26.4	1.4	.8	.1	0	23.2	0
28	26.4	1.3	.9	.1	0	23.2	0
CONTACT FILTER NO. 163.							
0	14.8	1.6	1	14.9	0.1	11.8	46.2
7	14.8	1.3	.6	6.6	0	10.8	0
14	15.1	1.1	.6	5.3	0	10	0
21	16.2	1	.6	1.6	0	9.4	0
28	17.4	.9	.4	2.5	.2	8.6	0

The trickling filter comes into direct competition with the double-contact system of sewage treatment, and it is necessary in every individual case to determine which of the two methods is most suitable. A comparison of the general features of the methods indicates that "on the whole the advantage rests with percolating filters" (Barwise, 1904). It has been pointed out (p. 73) that the trickling filter is simpler in theory, since it depends on the uninterrupted maintenance of a single process of aerobic oxidation. The construction of the body of the bed is cheaper, since the trickling filter need not be made tight and can be built entirely without walls. In operation the advantage probably rests with the contact bed, since the methods of distribution on the trickling filter, as so far developed, are expensive when working well and are liable to get out of order. Since, in principle, the operation of the trickling filter is simplicity itself, it seems that the mechanical difficulties involved should not be insuperable. The operation of trickling filters under severe climatic conditions apparently does not present serious difficulties. At Leeds winter weather produced no derangement of beds or distributors. In America the problem is somewhat more serious. The spray filters at the Columbus experiment station appeared to the casual observer (Winslow, 1905) to be working well in the severe winter of 1904–5; but it is certain that many of the complicated English distributors could never be operated in this climate.

With regard to rate and its converse, required area, the advantage s all on the side of the trickling filter. Double-contact beds 6 feet deep can not be operated at a rate over 0.5 million gallons per acre per day (calculated on the combined area of the two beds). With trickling filters, on the other hand, a rate three or four times as high may easily be attained. It was estimated at Leeds that 17 acres of trickling filters could be substituted for 165 acres of double-contact beds. With regard to the results produced, it must be concluded that the trickling effluent is generally superior to that of the double-contact bed. It is more turbid, but contains less organic matter and shows greater stability. Finally, the trickling filter is apparently not subject to so serious clogging as the contact bed. What little clogging occurs does not interfere with the capacity of the beds. Furthermore, deposits may easily be washed out of the filter, and this washing is to a great extent accomplished automatically at times of storm. It seems even possible that in some cases crude sewage may be handled by the trickling filter. Harding says:

> In the case of Leeds, I must say I do not see that there is any necessity for antecedent septic action, and if it proves practicable, as I think it will, to devise an automatic screening apparatus to take off the grosser solids, I think it would be possible to put crude sewage with finely divided solids direct upon a continuous filter and then have a settling tank at the end of the process, instead of at the beginning, or if the land is available, as it would be probably for the Leeds works, pass it overland for the purpose of mechanically separating—filtering—the suspended solids. [R. S. C., 1902 a.]

As evidence against the trickling process it should be noted that at Belfast Letts obtained very poor results with the trickling filter when filtering septic effluent. He used the Stoddart distributer, and his bed was 3 feet 9 inches deep, filled with 6-inch clinker. The purification was less than that obtained in parallel experiments at lower rates with a single-contact bed (Martin, 1905). The large size of the material used and the poor distribution seem to have vitiated this experiment. At Manchester a Stoddart filter of coarse clinker 2 to 3 inches, dosed with septic effluent, was tested in 1900. The effluents were of fair quality, but so turbid as to require settling (Manchester, 1901). Again, in 1902 a desultory experiment was made by dosing a second-contact bed with a sprinkler and leaving the outlet open. The secondary bed received six fillings a day, each occupying about an hour, so that it worked as a sort of trickling filter for a quarter of the time. A comparison of the effluent obtained in this way with that from the secondary bed operated as a contact bed showed that the latter process gave distinctly better results.

> It should be mentioned that several determinations which have been made show that there is more dissolved oxygen in the filtrate from bed D when this bed is worked continuously than when it is worked as a contact bed; there is, however, invariably more suspended matter in the former case. It is no doubt owing to this suspended matter that the percentage purification results above given are unfavorable to the sprinkler. [Manchester, 1903.]

With the exception of these incomplete and inconclusive studies the evidence of comparative tests favors the trickling process. At Leeds the matter was studied most exhaustively. The analytical results, as indicated by the figures quoted in Tables XXXVI and XLIX, were slightly better for the trickling process than for the contact beds, with rates threefold higher. While contact beds clogged badly even with septic effluent, the trickling beds, if built of coarse material (over 1½ inches), maintained their efficiency (Leeds, 1900). At York an elaborate series of comparative experiments was carried out in 1899 and indicated a marked superiority for the trickling filter (York, 1901). The principal analytical results are summarized in Table LII.

TABLE LII.—*Results of experiments at Naburn disposal works, York (York, 1901).*

Conditions.	Material.	Rate (million gallons per acre per day).	Analyses (parts per million).				
				Nitrogen as—			Oxygen consumed in 4 hours at 80° F.
			Total solids.	Free ammonia.	Albuminoid ammonia.	Nitrates.	
Closed septic tank and single-contact filters, August, 1899, to September, 1901	Sewage	0.5	872	33.6	5.1		31
	Effluent		571	19.7	1.8		11
Crude-sewage and double-contact beds, August to October, 1899	Sewage	.2	819	38	4.2		33
	Effluent		711	9.8	1.2	8.3	6.3
Ladder filter, August to November, 1899	Sewage	.4	897	38	4	0	33
	Effluent		950	25	2.5	0	18
Open septic tank and continuous filter, July, 1900, to August, 1901	Sewage	2.6	840	31.8	5.9		42
	Effluent		719	2.1	.6	113	6.6
Open septic tanks and double-contact beds, November, 1900, to August, 1901	Sewage	.2	876	24.7	6.3		42
	Effluent		645	4.6	.8	27.6	9.1

At Accrington trickling filters have been substituted for contact beds (Baker, 1904); and the same change is contemplated at Heywood (Bredtschneider and Thumm, 1904).

RECENT TENDENCIES IN SEWAGE-DISPOSAL PRACTICE IN ENGLAND, GERMANY, AND THE UNITED STATES.

Advances in the art of sewage disposal by processes of rapid treatment have been made almost wholly in England. It is natural that such should have been the case, since the concentration of population in that country renders some method of treatment necessary and since the lack of sandy soil makes the method of intermittent filtration impracticable. We have seen that the first steps were taken by Dibdin in the London and Sutton experiments of 1892-1896, which proved that the contact bed was capable of successfully treating sewage at high rates. Meanwhile Cameron's septic tank, installed at Exeter in 1896, was demonstrating the anaerobic process of preliminary treatment. At both Sutton and Exeter septic tanks followed by contact beds have since been installed (Baker, 1904). At London the system of chemical precipitation remains essentially as it was in 1892. The experiments carried out by Clowes and Houston in 1898–1901 led, however, to the recommendation that instead of this process there be substituted (*a*) sedimentation of mineral matter, (*b*) septic treatment in tanks of six hours' capacity, and (*c*) treatment in single-contact beds of coke 6 feet deep (Clowes and Houston, 1904).

The next important series of investigations was that carried out at Manchester. This city, the third metropolis of England, has a population of half a million and a daily flow of 42 million gallons of strong industrial sewage. Chemical precipitation was introduced in 1894, but the effluent created a nuisance in the ship canal into which it was discharged. No land was available for treatment, and in 1898 a commission consisting of Baldwin Latham, Percy Frankland, and W. H. Perkins began a series of experiments on the newer rapid methods. The first report, made in 1899 (Manchester, 1900 a), concluded that in spite of the presence of industrial wastes, the "bacterial system is the system best adapted for the purification of the sewage of Manchester." The experts believed that double-contact beds would produce a satisfactory effluent. "It may be taken broadly that in the first contact 50 per cent of the dissolved impurity is removed and that in the second contact 50 per cent of the impurity still remaining in the effluent is disposed of." They held that "in order that a bacterial contact bed may exercise its full powers of purification, it is necessary (*a*) that it should be allowed sufficiently frequent and prolonged periods of rest; (*b*) that the sewage applied to it should, as far as possible, be free from suspended matters; (*c*) that the sewage applied to it should be of as uniform a character as possible." They therefore recommended the installation of open septic tanks and double-contact beds. The secondary beds have not yet been constructed, but 46 acres of primary beds were in operation in 1904 (Baker, 1904).

The next important investigations were carried out at another great manufacturing center, Leeds. Here some experiments were made in 1870 which led to the adoption of chemical precipitation. In 1894 a special commission recommended broad irrigation, but sufficient land was not available. In 1897 investigations were begun by T. Hewson, W. H. Harrison, and T. W. Harding, and reports have been made in 1898, 1900, and 1905. It was found that the double-contact process gave good results with crude sewage and excellent results with septic effluent, but that serious difficulty was experienced in maintaining the capacity of the primary beds. Trickling filters of fine material gave good results, but clogged badly.

> On the other hand, continuous filtration over very coarse material of septic effluent and even of crude sewage has given interesting and remarkable results if the solids in suspension which come out in the effluent are settled after filtration. These solids are nonputrescible, can be readily settled, and the drying does not give rise to evil odors. It would seem that the coming through of these solids, which for the most part are not further reducible and largely mineral, insures the permanence of the coarse beds.
>
> It has been found practicable for long periods to work coarse, continuous beds 10 feet deep at the rate of 200 gallons per square yard, or 1 million gallons per acre per day, for septic effluent. At this rate results giving over 90 per cent purification are obtained after settlement of solids coming out in the filtrate; and although at this rate some of the solids are retained in the filter and there accumulate, they can be washed out by the increased flow which naturally arises with storm dilution. This possibility of dealing with storm waters is an important feature of the system.
>
> It would seem practicable to deal with crude sewage (previously strained through several screens); but in this case a depth of 12 feet of material would be required for Leeds sewage, which is not very strong. These latter experiments have not been carried on long enough to draw from them any definite conclusions. [Dibdin, 1903.]

It was finally recommended by the Leeds experts that coarse, trickling filters be installed, either preceded by septic or chemical treatment or followed by subsequent sedimentation. Construction has been delayed on account of legal and political obstacles.

Birmingham, the fourth largest city in England, with a population of 800,000, has faced similar difficulties. The discharge of sewage into the river Tame was begun in 1852. In 1859 experiments were carried out which led, in 1872, to the installation of chemical precipitation tanks and a sewage farm. Recently a most elaborate series of large-scale experiments, unfortunately never reported in print, have been carried out by Watson, the city engineer, and have indicated the application of biological processes. In 1900 a beginning was made by converting the precipitation basins into septic tanks. The sewage is now first settled for about four hours in tanks which are cleaned once a week. Thence it passes through the open septic tanks, which have a capacity of eight hours' dry-weather flow. No sludge had been removed from these tanks after three and one-half years of operation. The septic effluent is then treated on the largest farm in England, 2,830 acres in extent, of which 1,784 acres are in actual use. The results of these various processes in 1902 are shown in Table LIII.

TABLE LIII.—*Results of sewage purification at Birmingham, England* (*Watson, 1903*).

[Parts per million.]

	Solids.		Nitrogen as—			Oxygen consumed in 4 hours at 80° F.	
	Dissolved.	Suspended.	Free ammonia.	Albuminoid ammonia.	Nitrates.	Dissolved.	Suspended.
Average sewage	1,280	686	39.3	14.2	7	127	60.3
Sedimentation-tank effluent	1,312	346	37.7	10.9	7.3	149	92.5
Septic-tank effluent	1,180	274	48.1	8.3	3.1	121	71.8
Average land effluent	1,010	....	1.7	.1	5.7	19	....

It is planned in the future to settle the septic effluent in Dortmund tanks and to purify it by passage through trickling beds, of which four were in operation in 1904 (Baker, 1904).

Experiments second in importance only to those mentioned have been carried out at other large cities in England. At Leicester in 1898–99 a series of investigations was made by E. G. Mawbey involving 16 combinations of detritus tanks, settling tanks, single, double, and triple contact beds, and land treatment. Most of these experiments were unfortunately of very short duration. At present the Beaumont-Leys sewage farm of 1,700 acres is still in operation, but the installation of settling tanks and single-contact beds is planned for the near future (Leicester, 1900). Huddersfield has a serious problem in the presence of large amounts of industrial waste from the scouring and dyeing of wool; but it was shown in a series of experiments carried out between 1898 and 1900 by J. L. Campbell that chemical treatment, sedimentation, and contact treatment would solve the difficulty satisfactorily (R. S. C., 1902 b). At certain hours of the day a single treatment would be sufficient, while at other times secondary beds should be used. Triple-contact beds treating crude sewage gave good purification, but clogged badly. At Oldham studies carried out by J. B. Wilkinson from 1898 to 1900 led to the adoption of sedimentation and single-contact beds (R. S. C., 1902 b). At York chemical treatment has proved unsatisfactory, and since 1899 investigations have been carried on by A. Creer, which, as shown in Table LII, indicated that septic tanks and trickling filters would best solve the problem. Large-scale experimental filters have been put in operation, but the final construction is not yet under way (Baker, 1904).

The review of existing conditions in 1904 published by M. N. Baker (1904) describes some of the most interesting plants in actual operation. At Manchester, Sutton, Exeter, Yeovil, Barrhead, Oldham, and Burnley he found septic tanks and contact filters. At Birmingham, Salford, Accrington, and York trickling filters were in operation. There is a strong general tendency to the conversion of old chemical-precipitation systems into septic tanks, except at Glasgow, where the former process is to be maintained. Sewage farming is not extending, although it has its strong advocates and many of the farms now in use operate satisfactorily. The popularity of double-contact beds, at a maximum five years ago, seems already on the wane. Trickling filters, either preceded or followed by septic treatment or sedimentation, are growing in favor (Baker, 1904).

The general progress of sewage disposal in England has been seriously checked by the local government board, which enjoys extraordinary authority over any exercise of the borrowing power on the parts of municipal corporations. The sewage of towns commission had reported in 1865 that "the right way to dispose of town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided." The rivers pollution commission in its five reports from 1870 to 1874 recommended intermittent filtration as the best method for sewage treatment, with broad irrigation next and chemical precipitation last. The metropolitan sewage commission of 1882 reported in 1884 that chemical precipitation should be adopted by London and that the effluent should finally be treated on land. The local government board, on the strength of these precedents, has maintained a position of extreme conservatism, requiring, save in exceptional cases, that "any scheme of sewage disposal for which money is to be borrowed with their sanction should provide for the application of the sewage or effluent to an adequate area of suitable land before its discharge into a stream." The following detailed rules of the board were set forth in a circular issued in 1900: "In any sewage works three times the dry-weather flow must be treated, and an equivalent amount in addition must be provided for by special storm-water filters. Septic tanks or sedimentation basins must have a capacity equal to the dry-weather flow if followed by double-contact beds, and 50 per cent larger if followed by single-contact or trickling filters. Contact beds must not be over 4 feet deep and may receive two fillings a day, or three if automatic devices are provided. Their capacity shall be figured on an open space of 33 per cent with preliminary septic treatment or sedimentation and of 25 per cent with crude sewage. Trickling filters must be at least 6 feet deep and may operate at a rate of 1 million gallons per acre per day with crude sewage, which may be doubled with sedimented sewage or septic effluent. The effluent from either the contact or the trickling process must be subsequently treated on land, 1 acre being allowed for every 1,000 persons contributing sewage. With crude sewage on land 150 persons per acre is the limit."

In view of the experiments at London and Sutton and at Leeds and Manchester, such rules were an almost intolerable burden, and with these facts in view a new royal commission was appointed in 1898, with the Earl of Iddesleigh as chairman, to determine "what method or methods of treating and disposing of sewage (including any liquid from any factory or manufacturing process) may properly be adopted." This commission made a first interim report of three volumes in 1901, a second on special chemical and bacteriological problems in 1903, and a third in two volumes on the treatment of trade effluents in 1903. Of a fourth report four volumes were issued in 1903 and 1904, three on the pollution of tidal waters, with special reference to contamination of shellfish, and a fourth (in five parts) on the land treatment of sewage. The first interim report of

901 accomplished the chief work of the commission, since it conained the conclusion that—

> It is practicable to produce by artificial processes alone, either from sewage or from ertain mixtures of sewage and trade refuse—such, for example, as are met with at Leeds nd Manchester—effluents which will not putrefy, which would be classed as good accordng to ordinary chemical standards, and which might be discharged into a stream without ear of creating a nuisance. We think, therefore, that there are cases in which the local overnment board would be justified in modifying, under proper safeguards, the present ule as regards the application of sewage to land. [R. S. C., 1901.]

The conclusions of the royal sewage commission throw open the way for progress, and the developments of the next decade may be watched with interest.

On the continent of Europe progress in sewage disposal has been much less rapid than in England. Germany is ahead of other countries in this respect, but even here the problem has not pressed heavily. The population is less dense and the rivers larger than in England. The installation of purification systems was slow, and when they were found necessary land for irrigation was generally available. The knowledge of the process of sewage farming dated from a visit to England made in the early seventies by a Berlin commission headed by Rudolf Virchow, and inspiration along more modern lines has similarly come from England. In 1897 of 43 English cities with over 70,000 population 23 treated their sewage by irrigation or chemical precipitation. In Germany at the same time there were only nine cities with over 70,000 population having disposal systems, of which three were precipitation works and six sewage farms (Kinnicutt, 1898).

The most important experimental work carried out in Germany has been that of the experiment station of the Hygienic Institute of Hamburg. This was founded in 1894 to test various sewage-purification processes and placed under the charge of Doctor Dunbar as director. Experiments on the contact process were begun in 1897, and the studies at this station have done more than any others to elucidate the theory of the contact bed. The general results indicated that good effluents could be obtained from single-contact beds of fine material, but that under such conditions clogging occurred, which must necessitate the removal of the material for cleaning several times a year (Dunbar and Thumm, 1902).

Meanwhile Schweder had installed in 1897 an experimental septic tank and contact bed at Grosslichterfelde to treat part of the sewage of Berlin. A commission appointed by the Prussian ministry of the interior studied this plant in 1897–98 and arrived at the same conclusion which Dunbar had reached in the case of Hamburg (Bruch, 1899).

In 1901 the royal testing station for water supply and sewage disposal was organized at Berlin, and its annual communications since 1902 have furnished a succession of papers of the greatest value. Unfavorable results were first reported from contact beds at Tempelhof and Charlottenburg. In 1901 Zahn (1901) on behalf of the station carried out a series of investigations at Charlottenburg (Westend) which showed that nonputrescible effluents could be obtained with single contact. Experiments by Schury (1905) at Stuttgart led to similar results, septic treatment and single contact giving good results, little improved by secondary treatment. Trickling filters proved slightly better than contact beds.

The general trend of the German experimental work has till recently been in favor of single-contact treatment in beds of fine material, to be dug out and cleaned at intervals. Opinion is not favorable to the septic tank. Considerable interest has been recently manifested in the trickling filter, especially at Berlin. In spite of the great importance of the Hamburg work in relation to theoretical questions, the writers can not feel that the German experiments have furnished a fair test of the modern biological processes. It is true that German sewage is strong and contains large amounts of industrial wastes, yet in addition to these facts it seems even to local observers that the experimental filters have not been operated with the judgment and skill necessary to secure the greatest practical efficiency (Thumm, 1905).

Actual practice in Europe outside of England is still largely confined to chemical treatment and irrigation. In Germany in 1904, according to the official charts exhibited at the St. Louis Exposition, there were 254 cities with over 15,000 inhabitants. Twenty of these had no sewerage system. Of the remainder, 132 discharged their sewage into water, 84 treated it by various chemical processes, and 18 disposed of it on irrigation areas. Bredtschneider and Thumm were sent by the Berlin royal testing station and the city of Charlottenburg to study English conditions in 1903, and their report (Bredtschneider and Thumm, 1904), together with the results of the Hamburg and Berlin experiments, is likely to bear fruit in the near future. In France, too, active interest is manifested in the newer processes. A commission including MM. Calmette, Beckman, and Lannay visited England in 1900 to examine the works there in operation, and later experiments showed that the sewage of Lille could be satisfactorily treated in septic tanks and double-contact beds (Calmette, 1901).

In the United States sewage-disposal practice necessarily varies widely in different localities. New England, covered with a mantle of Glacial drift, finds the Lawrence method of intermittent filtration through sand eminently satisfactory. Following the construction of the beds at Framingham in 1889 and at Gardner and Marlboro in 1891, plants of this type have been rapidly added in Massachusetts till in 1903 there were 23 intermittent-filtration areas in the State

Massachusetts, 1904). In Connecticut in 1902 there were nine plants in operation, all sand filter beds (Connecticut, 1903).

West of the Appalachian Mountains soil conditions change, and available areas of sand become more and more difficult to obtain. The septic tank is frequently called in to remove solids and make possible the treatment of sewage at more rapid rates. The plants at Saratoga, N. Y. (Barbour, 1905), Lake Forest, Ill. (Alvord, 1902), and Wauwatosa, Wis. (Alvord, 1902), are good examples of this type.

In the Middle West the newer biological processes are rapidly gaining a foothold.

The first septic tanks at Urbana, Ill. (1894), and Champaign, Ill., have been mentioned. Septic tanks have since been installed at Kewanee, Ill. (1898), Fond du Lac, Wis. (1901), Madison, Wis. (1901), Mansfield, Ohio (1902), and a score of other places. The construction of contact beds began about 1900 and some dozen plants are now in operation, the most important being at Mansfield, Ohio (Pratt, 1905). In 1905 there were in Ohio 32 purification plants, of which 19 were sand filters and 7 contact beds; 13 made use of septic tanks at some stage in the process (Pratt, 1905). The only trickling filter of large size is at Madison, Wis.

Most of the plants in the Middle West are small and in many cases their maintenance is grossly neglected (Winslow, 1905). The city of Columbus is the first American municipality to approach the subject with a serious intention of finding the method of treatment best suited to local conditions. Here, under the direction of Hering and Fuller, a testing station was equipped in 1904, and a force of experts, including G. A. Johnson, W. E. Copeland, and A. E. Kimberley, carried out for a year an elaborate series of experiments. The station included a laboratory, one set of open tanks for preliminary treatment, and three sets of filters, with a gallery under a frame covering for each set. The sewage, amounting to about 350,000 gallons per day, was raised by a centrifugal pump to a screen chamber with two movable screens of three-eighths inch diagonal wire mesh. Next it passed to one of the tanks for preliminary treatment. These were seven in number, each 40 feet by 8 feet, 8 feet deep at the upper end and 9 feet deep at the lower end, built of wood lined with galvanized iron. The first two tanks were called grit chambers, the sewage flowing through in about one and one-half hours. The other five tanks were either "plain sedimentation" or septic tanks, in which the sewage remained eight hours or more, the difference being that the former were emptied and cleaned whenever septic action began. In the septic tanks periods of eight, sixteen, and twenty-four hours were compared.

The sewage after treatment by one of these three preliminary processes (grit chamber, plain sedimentation basin, or septic tank) was purified by treatment in one or more of thirty-five experimental filters.

These were cypress tanks 6 feet deep; one was 11 feet in diameter, four 12 feet 10¾ inches in diameter, and the other thirty 7½ feet in diameter. They were all open filters and arranged for the most part in two blocks of two rows each, with a covered dosing and sampling gallery between the rows, in which all the engineering details of operation were regulated with the greatest accuracy. Twenty-one were intermittent sand filters, two primary and four secondary contact beds of broken limestone, two coke strainers, and six trickling filters. With this plant the widest possible series of combinations was tried, including sand filters, trickling filters, and contact beds alone, either of these preceded by plain sedimentation or septic treatment, and sand filters preceded by contact or trickling filters. The results of the experiments have led to the recommendation of septic treatment, followed by trickling beds.

Plans of the sewage-purification work for a nominal flow of 20 million gallons per day have been presented to the State board of health. The plans propose septic tanks followed by sprinkling filters. The septic tanks will be 12 feet in depth, uncovered, and will have a capacity of about 8 million gallons. The sprinkling filters will be about 10 acres in area, of broken stone, 5 feet in depth, laid on hollow free-draining bottom, with sprinkling nozzles 15 feet, center to center, designed under a 5-foot head to spray the septic sewage over the surface of the broken stone, at a net rate of 2 million gallons per acre per day. The effluent from these filters will be collected in settling basins with a capacity of 4 million gallons. [Griggs, 1905.]

In the extreme West a third set of conditions confronts the sewage expert. The arid climate here makes the sewage of special value for irrigation and the sparseness of population renders sewage farming the most profitable means of treatment. Following the early broad-irrigation areas at Cheyenne, Wyo. (1883), Greeley, Colo. (1890), Hastings, Nebr. (1892), Los Angeles, Cal. (1892), and Trinidad, Colo. (1892), a dozen or more plants have been laid out and are in operation, the largest in 1904 being at Los Angeles, Cal., Salt Lake City, Utah, and Hastings, Nebr.

Chemical-precipitation plants, built before the newer processes were developed, are maintained at Alliance and Canton, Ohio, and at other places to avoid the cost of change. At Providence, R. I., on account of special local conditions, this process seems well adapted for continued use.

In a comprehensive review of conditions in the United States, Fuller (1905 a) states that of 1,524 cities and towns with a population over 3,000, 1,100 have sewerage systems and 90 have purification plants. Among these 90 plants are 14 irrigation areas, 41 intermittent sand filters, 13 chemical-precipitation works, 29 septic tanks, and 10 rapid filters of coarse materials. The fact that of a population of 28,000,000 connected with sewerage systems the sewage of 20,400,000 is discharged into fresh water and of 6,500,000 into the sea furnishes some indication of the problem which must be met in the near future.

EXPERIMENTS ON THE PURIFICATION OF BOSTON SEWAGE, 1903-1905.

THE SEWAGE EXPERIMENT STATION.[a]

The sewage experiment station of the Massachusetts Institute of Technology is situated in the southeastern portion of the city of Boston, near the corner of Albany street and Massachusetts avenue, at the point indicated by the star on the map (fig. 9). Connection is made with the 9-foot sewer of the Boston main drainage system at a point on Massachusetts avenue about 200 feet below the entrance of

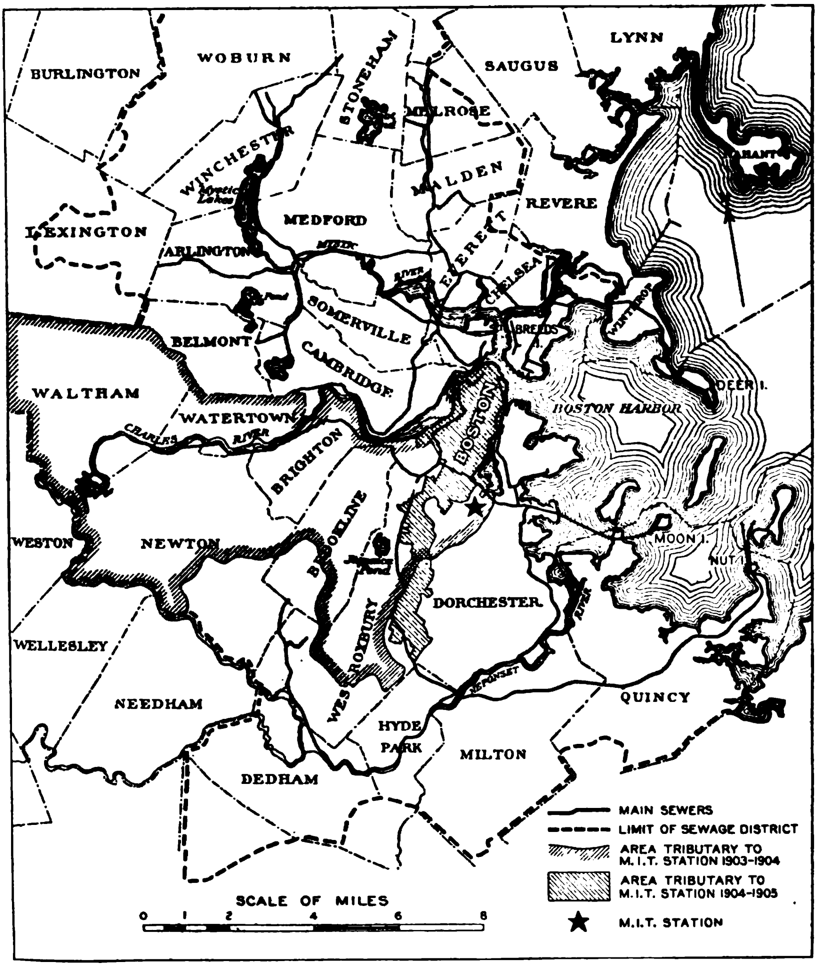

Fig. 9.—Map of Massachusetts metropolitan sewerage district.

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[a] The foundation of this station and the object of the experiments are described in the introduction (pp. 5-9).

the Albany street intercepting sewer. Prior to October 14, 1904, sewage from the whole of Boston south of the Charles, with the exception of the Dorchester and South Boston districts, together with sewage collected by the south metropolitan sewerage system from Waltham, Newton, Watertown, Brighton, and Brookline, flowed past the station intake. This contributory area is shown in fig. 9. In 1903-4 the flow above the station was more than 50 million gallons a day from a district with a contributing population of 350,000, sewered for the most part on the combined system. Since October, 1904, the completion of the new high-level sewer and of the Ward street pumping station has resulted in the diversion of all the sewage from the metropolitan district, outside of Boston proper, to the new sewer, diminishing the average daily flow past the station intake by about one-fourth. The location of the station and of the intake pipe with reference to the sewers is best seen in the accompanying ground plan (fig. 10).

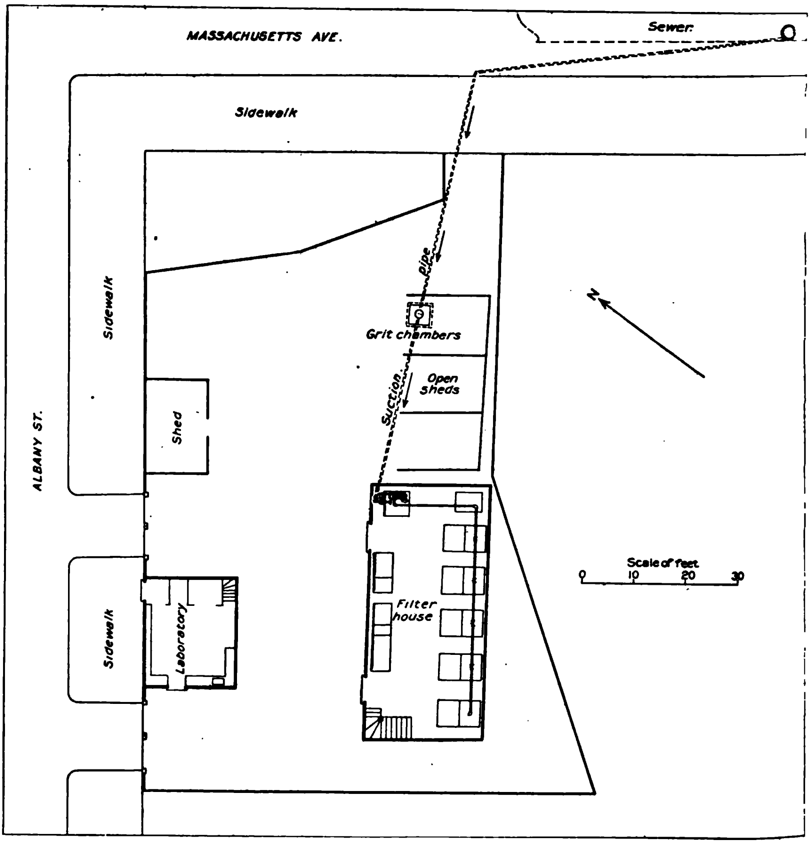

FIG. 10.—Plan of Massachusetts Institute of Technology experiment-station grounds and buildings.

A 2½-inch galvanized-iron suction pipe runs directly to the station pump from a point in one of the sewer manholes about 10 feet below the surface of the street. To the lower end of this pipe is coupled a 20-foot length of rubber suction hose of 3 inches internal diameter. This hose would reach to the bottom of the sewer in the absence of any flow, but is carried by the strong current to a nearly horizontal position at its lower end, so that it is suspended at about mid-depth. The flow is so strong that the sewage is well mixed throughout. At the end of the hose is a strainer made from a 3-foot length of 6-inch wrought-iron pipe in which eight ½-inch longitudinal slots have been cut from a point near one end through the other end. The open end is protected by a plate fastened within and having deep notches cut radially to correspond with the slots in the pipe. Such a device is found to be largely self-cleaning, allowing a free movement toward the end, of any material which is drawn lightly into one of the slots. Strainers of the ordinary type clog badly. Even with the slotted pipe the end must be hauled up each day, or oftener, and the rags and other material collected on it removed. The rubber suction pipe is joined to the iron pipe above it by a "quick-as-a-wink" coupler, a clamping device sometimes used in fire apparatus for making quick connections without screwing. With this coupler the entire suction pipe can be disconnected and hauled up without bending it—a method which it is necessary to adopt in cleaning the end at times of very high water. Just before reaching the pump the suction pipe passes through a grit chamber, where it deposits the heavier particles of sand and cinders. This chamber was put in at the suggestion of Mr. Leonard Metcalf, who furnished its design and other friendly suggestions. It consists of a cast-iron cross of stock water-pipe pattern. The diameter of the large arm, which rests vertically and constitutes the chamber, is 19 inches and its depth 16 inches. The other arm is 2½ inches in diameter and connects with the suction pipe by flanges. Blank flanges form the top and bottom of the chamber and are bolted on and made tight by rubber packing, so that the top of the chamber may be readily removed for cleaning. A vertical grating of half-inch square iron bars, placed so as to give a clear space of half an inch between them, divides the chamber into two parts and serves to retain any rags or other large material which may have escaped the suction strainer. The chamber is placed on the line of the suction pipe 8 feet below the surface of the ground and is covered by a heavy frame structure of pyramidal form, 6 feet square on the bottom. From the grit chamber the suction pipe runs direct to the cellar of the filter house. Details of the grit chamber are shown in fig. 11.

The filter house is a two-story frame structure, the interior arrangement of which is made clear in figs. 12, 13, and 14. Fig. 12 is the ground-floor plan, showing the arrangement of the filter tanks and the pump pit. Fig. 13 is a plan of the second floor, indicating the position of the supply tanks, septic tanks, and sand filters. Fig. 14 is a midsectional elevation bringing out the vertical arrangement of the various parts of the plant.

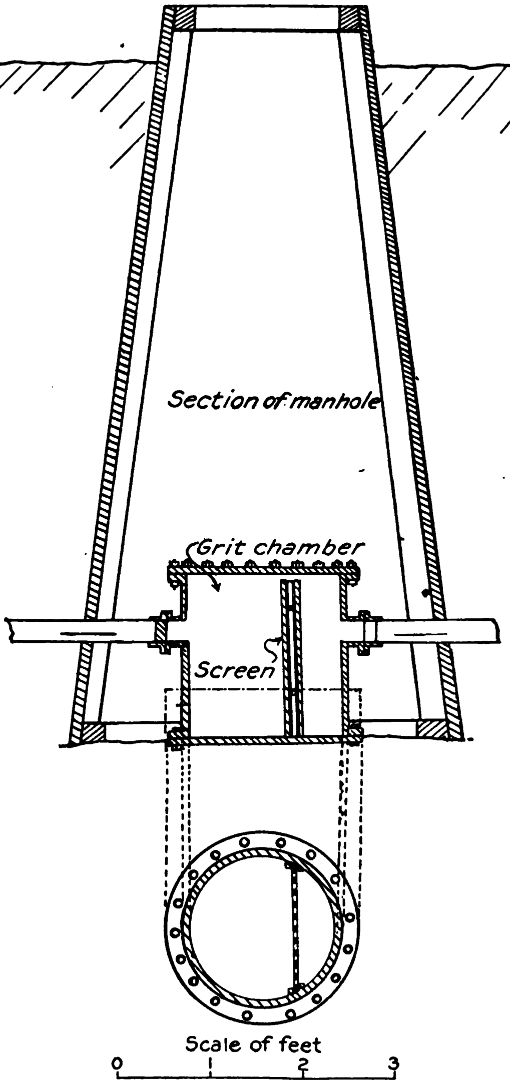

FIG. 11.—Detail of grit chamber.

The position of the pump is shown in fig. 12. It is a 4 by 6 duplex Warren power pump driven by a 2-horsepower induction motor under 110 volts alternating current of 66 frequency. The plunger is of the cup type. It is found that this form protects the composition lining of the cylinder much more perfectly than a packed plunger.

he valves are of the clapper type, with rubber packing, which is equently renewed. The pump is placed in a pit 7 feet below the floor of the filter house. The total suction lift is 16 feet, reckoned from the average dry-weather elevation of the sewage surface to

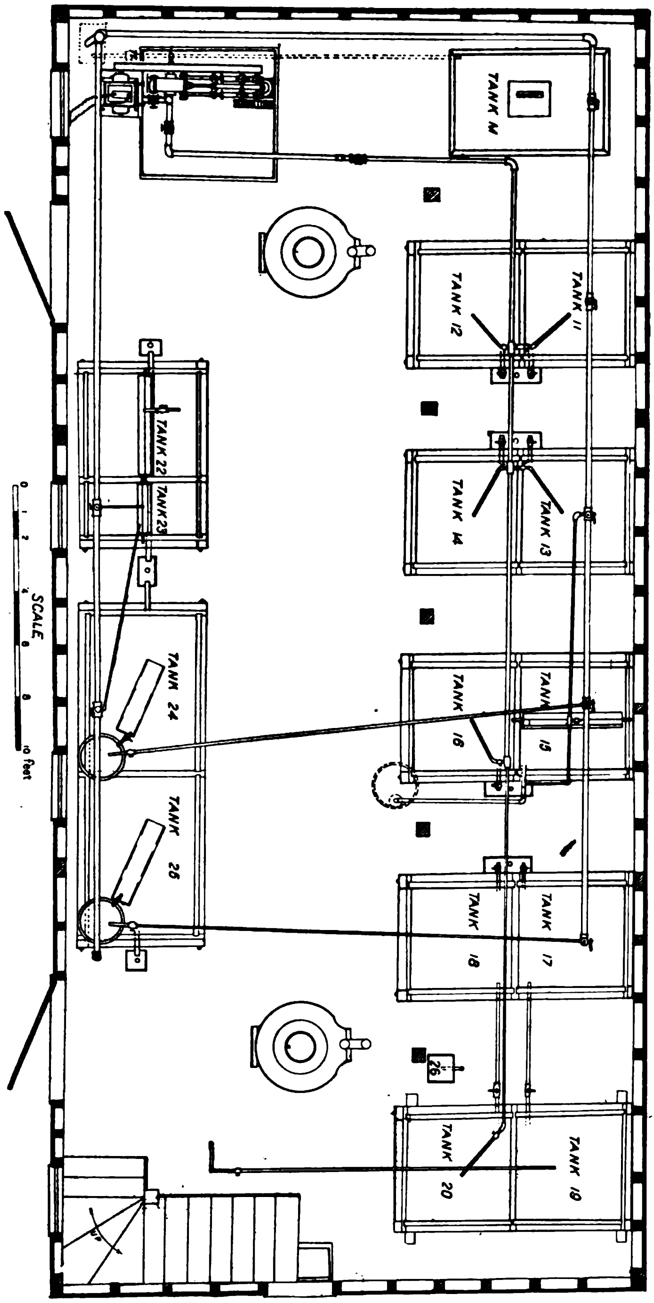

FIG. 12.—Plan of ground floor of filter house.

the pump valves. This lift may be increased to 20 feet at times of low flow. The pump is supplied with a vacuum gage, which

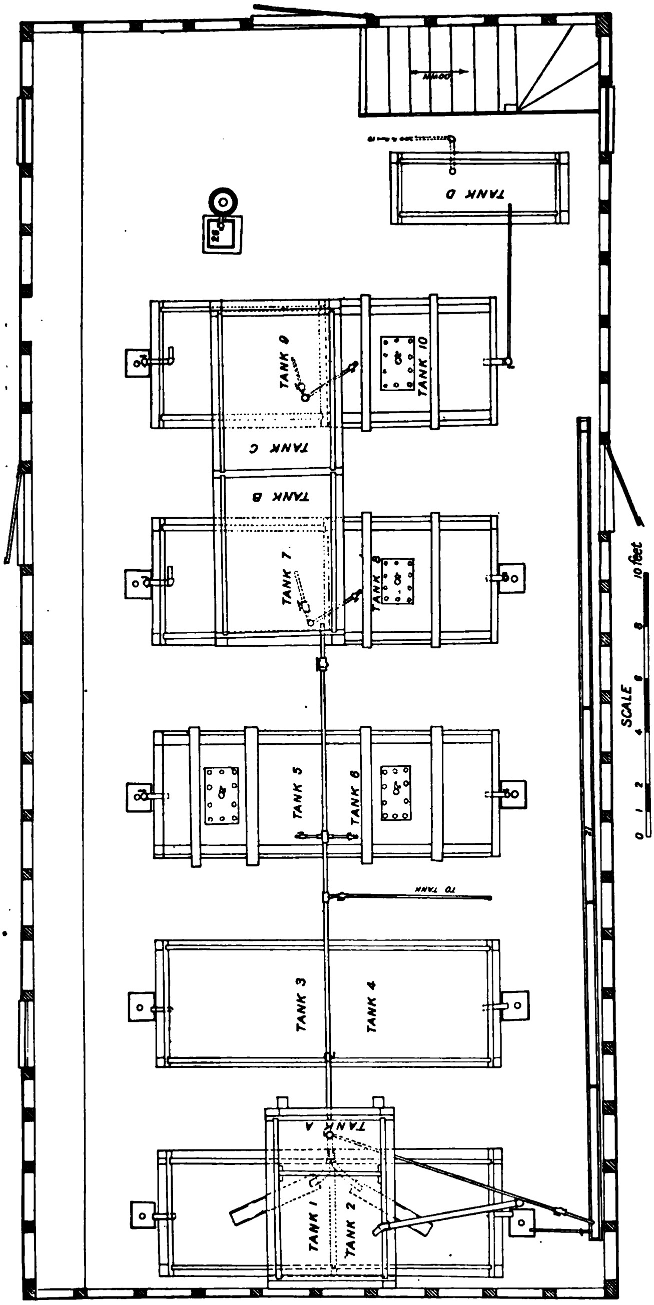

FIG. 13.—Plan of second floor of filter house.

enables the attendant to see at a glance whether or not the valves are performing their duty and whether any stoppage of the strainers has occurred.

The sewage is delivered through a 2-inch force main to supply ank A, best shown in the sectional elevation (fig. 14). The lift rom the pump valves to the tank is 25 feet. The supply tank is by 6 feet in area and 2 feet deep. The sewage enters the tank over the side near one end, passes over the weir shown in the section, and thence through pipes to supply tanks B and C and to the various filters. Tanks B and C are each the size of A and are connected with each other by holes through the dividing partition. They serve primarily to give a constant flow through the septic tanks, which are placed at a lower level on the same floor, and to the trickling filters on the floor below. The two tanks have a combined capacity of about 700 gallons, which is a two hours' supply for the continuously working tanks and filters.

Filters Nos. 1 and 2 are sand filters. Tank No. 1 is a cypress tank by 6 feet in area and 3 feet deep. It contains 2 feet of common Glacial drift sand with an effective size of 0.17 mm. and a uniformity coefficient of 3.5. This layer of sand rests on 6 inches of underdrain material graded from 4-inch cobbles at the bottom to buckwheat gravel just beneath the sand. The outlet of the filter is a -inch iron pipe open at all times and not trapped. Filter No. 2 is like filter No. 1 in all respects, except that it contains a layer of sand but 1 foot thick over the underdrain material. The two tanks are built together, as shown in fig. 13.

The six septic tanks, numbered 5 to 10, are also built in pairs and are of the same dimensions as the sand-filter tanks, namely, 4 by 6 feet and 3 feet deep. Tanks Nos. 7 and 9 are uncovered. The other four are covered as tightly as possible with wooden covers. These covers are not absolutely gas tight. Tank No. 6 is filled with crushed stone about 1½ inches in diameter. All the tanks and filters on this floor, except No. 10, drain into small catch basins connected with the main drainpipe underneath the floor. This arrangement is shown in fig. 14. Each drainpipe may be closed off from the main drain by a cock just above the latter and the tank effluent diverted to the filters below. Tank No. 10 drains directly into the small tank D, which is 2 by 6 feet and 2 feet deep. This is used to flood a contact filter below.

Filter tanks Nos. 11 to 16 are all cypress tanks 4 feet square and 6 feet deep, built together in pairs. Tanks Nos. 17 to 20 are of the same area, but only 4 feet deep. The pair Nos. 19 and 20 are at a higher elevation, so that their effluents can flow to the other pair, Nos. 17 and 18, respectively.

Tank No. 15 is a trickling filter, receiving the septic sewage from tank No. 5. Tanks Nos. 11 to 14 and Nos. 16 to 20 are contact filters. Tank No. 11 is filled with coke 2 to 3 inches in size; tanks Nos. 12, 15, 19, and 20 with crushed stone 1 inch to 1½ inches in size, and tanks Nos. 13, 16, 17, and 18 with one-fourth to one-half inch crushed stone. Tanks Nos. 17 and 19 constitute one double-contact system and Nos. 18 and 20 another. Tank No. 14 is the only one which has been altered during the experiments. During the first

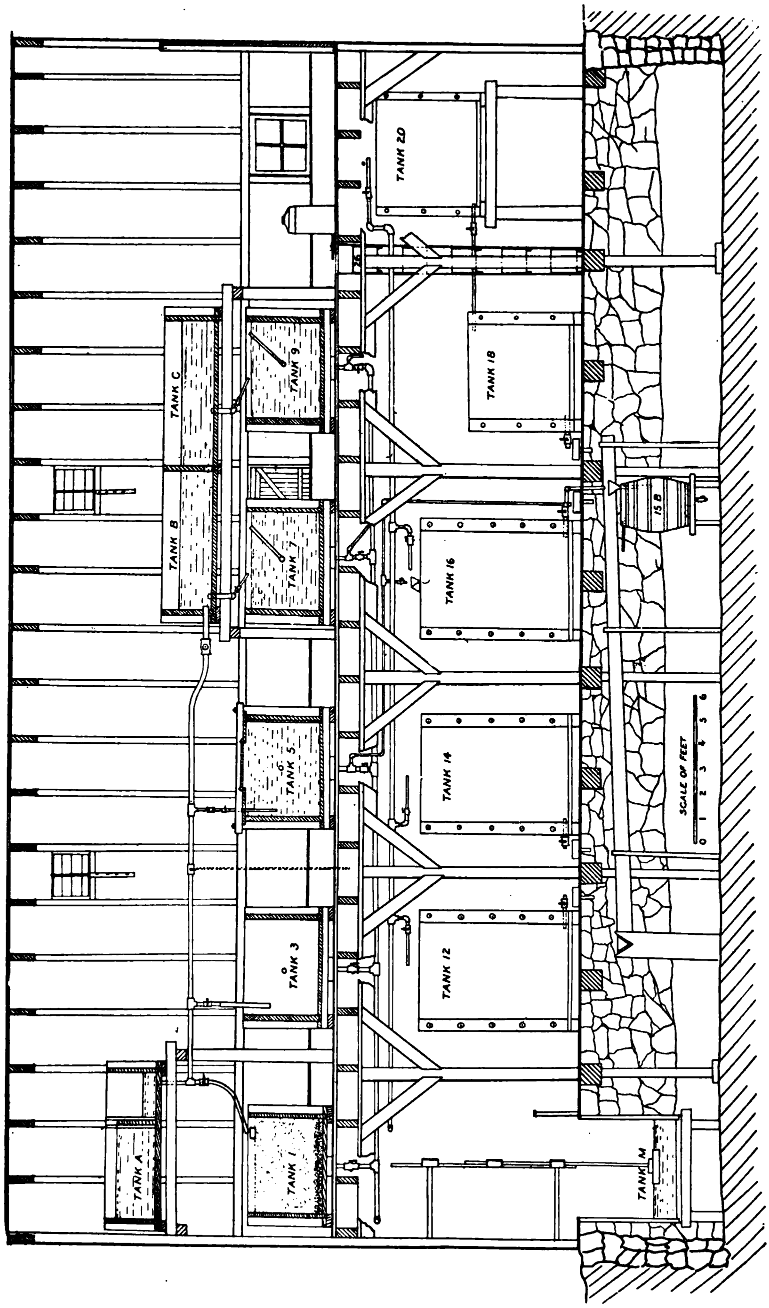

FIG. 14.—Section of filter house.

year it was filled with crushed stone between one-half and 1 inch in diameter. In June, 1904, it was emptied and filled with Raritan facing brick, 1½ by 4 by 12 inches, so laid in even tiers as to give the maximum of open space. Tank No. 22 is 4 by 4 by 6 feet, and No. 23 is 4 by 2 by 6 feet, the two tanks forming a pair. They are filled with 1 inch to 1½ inches crushed stone and are operated as trickling filters. Sand filters Nos. 24 and 25 are exact counterparts of filter No. 1. The filters on the lower floor all drain into catch basins similar to those on the upper floor already described. These empty directly into a main drain underneath the floor. In the case of filters Nos. 15 and 22 the effluent runs into a barrel provided with an overflow. These barrels provide a two hours' storage for the effluents, so that the effect of that period of sedimentation may be studied. The barrel under filter No. 15 is shown in fig. 14. Tank M is used as a measuring tank. It is fitted with a float gage, carefully calibrated, reading by means of a vernier to the nearest gallon. The principal statistics of the tanks and filters are brought together in Table LIV for convenience of reference.

TABLE LIV.—*Statistics of experimental tanks and filters.*

No.	Dimensions (feet).	Description.	Material.	Size.
1	4 by 6 by 3	Intermittent sand filter	Sand	0.17 millimeter.
2	4 by 6 by 3	do	do	Do.
3	4 by 6 by 3	Sampling tank		
4	4 by 6 by 3	do		
5	4 by 6 by 3	Septic tank		
6	4 by 6 by 3	do	Stone	1 inch to 1½ inches.
7	4 by 6 by 3	do		
8	4 by 6 by 3	do		
9	4 by 6 by 3	do		
10	4 by 6 by 3	do		
11	4 by 4 by 6	Contact filter	Coke	2 to 3 inches.
12	4 by 4 by 6	do	Stone	1 inch to 1½ inches.
13	4 by 4 by 6	do	do	¼ to ½ inch.
14	4 by 4 by 6	do	Stone Brick	½ to 1 inch.
15	4 by 4 by 6	Trickling filter	Stone	1 inch to 1½ inches.
16	4 by 4 by 6	Contact filter	do	¼ to ½ inch.
17	4 by 4 by 4	do	do	Do.
18	4 by 4 by 4	do	do	Do.
19	4 by 4 by 4	do	do	1 inch to 1½ inches.
20	4 by 4 by 4	do	do	Do.
22	4 by 4 by 6	Trickling filter	do	Do.
23	4 by 2 by 6	do	do	Do.
24	4 by 6 by 3	Intermittent sand filter	Sand	0.17 millimeter.
25	4 by 6 by 3	do	do	Do.

According to the plan of the experiments each unit differed from each of several other units by only one variable condition. In this way the results of the whole series may be studied together as one experiment, and it is possible to note the results of changing any one variable condition, the others being constant. Among the variables which have been studied in this way are, first, of course, the various types of purification processes and the coincident necessary variation in the rate of filtration. Then under each principal type of process two or more of the following conditions have been compared, the variables, as stated, being introduced one at a time: Different kinds and sizes of material, different depths of bed, single versus double contact, fresh versus septic sewage of different ages, and open versus closed septic tanks. With the sand filters four combinations have been studied, each differing from each of the others by only one of these variables; with contact filters, six combinations; with trickling filters, three; and with septic tanks, three, which, together with one primary comparison of the main types, makes a total of seventeen combinations of the variables mentioned.

On the sand filters Nos. 1 and 2 the volume of sewage applied has been measured by a float in the supply tank over the filter. The pump was stopped while these filters were receiving their doses. Sand filters Nos. 24 and 25 were dosed from the barrels shown in fig. 12. These barrels contain the exact amount of one dose. Sewage was distributed over the surface of the sand filters by means of small wooden troughs with side openings at intervals. Application of sewage to the contact filters was made by means of a single half-inch pipe discharging horizontally over the filter. The filling was in all cases continuous, about half an hour being allowed for the process. The amount of sewage applied to the contact filter is of course its own liquid capacity multiplied by the number of doses applied daily. To obtain this value and also to study the progressive loss of capacity of contact filters under various conditions very careful measurements of the capacity of all the filters have been made at weekly intervals. For this purpose the measuring tank M was used. Connection with the filter outlet was made by means of a rubber hose, and the total effluent of the filter was run into the measuring tank after the height of sewage within the filter had been noted.

The trickling filters were dosed by means of tipping buckets, long V-shaped troughs divided by a longitudinal partition into two equal parts. As one side fills the weight of sewage overbalances the system and the bucket tips, emptying the full side and bringing up the other side so that it receives the flow and tips in its turn. In this way the sewage is splashed in successive doses over the two halves of the filter alternately.

By connecting an ordinary cyclometer to this tipping bucket it has been possible to record the number of tips and indirectly the total flow. The apparatus was originally rated, and occasionally checked, by allowing the effluent to flow into the measuring tank for a period and comparing the readings of the cyclometer with those of the float gage.

The closed septic tanks were regulated at their outlets, free communication being allowed with the supply tanks overhead. The open tanks were maintained at a constant level by overflow pipes and were regulated at the inflow pipe. All these tanks were under the constant observation of an attendant both day and night, and the rates of flow were determined at frequent intervals by filling a 10-quart pail.

In sampling, a representative sample of the crude sewage was obtained by allowing a portion of the regular pumpage to flow slowly into a tank of 540 gallons capacity, filling the tank in about three hours during each morning. The sewage in the tank was then thoroughly mixed and sampled. Trickling effluents and sand-filter effluents were collected whenever running. Contact-filter effluents were collected at about the middle of the discharge. Analyses of each effluent were made weekly and of the sewage five times a week.

ANALYTICAL METHODS AND INTERPRETATION OF RESULTS.

In the comparison of two sewages from different localities the term "strength" is often used in such a loose way that its significance is more or less obscure. Strictly the strength of a sewage is measured by the amount of certain elementary constituents which it contains, as, for example, the amount of nitrogen present. Only on such a basis can any fair comparison of sewages be made. The use in this connection of constituents so partial and changeable as the free or albuminoid ammonia or the oxygen consumed is misleading. These constituents are in a state of constant change in any given sewage, and hence can not satisfactorily determine its real strength. This point is well illustrated by the analyses in Table LV, taken from the reports of the Massachusetts State board of health for 1903 (Clark, 1904). The first line represents a nine months' average of weekly analyses of the Lawrence street sewage taken directly from the sewer—a fresh sewage. The second line represents analyses of the same sewage for the same period after it had been pumped through about half a mile of pipe and subjected to sedimentation and septic action.

TABLE LV.—*Comparison of fresh sewage at Lawrence with the same sewage after passing through long pipe, April to December, 1903 (Massachusetts, 1904).*

[Parts per million.]

	Nitrogen as—		
	Free ammonia.	Albuminoid ammonia.	Total organic.
Lawrence street sewage	18.1	5.8	23.4
Station sewage	39	5.2	13.3

The increase in the free ammonia and the decrease in the total organic nitrogen are characteristic of what occurs in stored sewage. Such partial values as are given by determinations of albuminoid ammonia and oxygen consumed do not, therefore, stand in any constant relation to the total figures—for organic nitrogen and carbon, respectively—and hence in different sewages give different proportions of the whole.

Total nitrogen and total carbon values are, then, to be desired in the study of sewage purification. The latter are out of the question, since there is no available method for this determination sufficiently simple for routine use. Total nitrogen values have also been generally ignored until very recently, and these experiments were nearly half completed before their paramount importance became evident. Throughout the present series of studies, therefore, the old determinations of free and albuminoid ammonia and oxygen consumed have been maintained. These must be taken for what they may be worth as roughly representative of the total organic matter.

In this connection it is useful to remember that both the free and the albuminoid ammonia in sewage increase with age, and that the ratio of albuminoid ammonia to organic nitrogen increases at a corresponding rate. In a fresh sewage the albuminoid ammonia is roughly one-third the free and the organic nitrogen generally over three times the albuminoid. As the albuminoid-free ratio decreases the organic-albuminoid ratio decreases at almost the same rate, and Fuller (1903) has found that the former ratio is roughly about one-twelfth the latter; put into algebraic form this becomes—

$$\frac{12 \times \text{albuminoid nitrogen}}{\text{ammoniacal nitrogen}} = \frac{\text{organic nitrogen}}{\text{albuminoid nitrogen}}$$

whence

$$\text{organic nitrogen} = 12 \times \frac{(\text{albuminoid nitrogen})^2}{\text{ammoniacal nitrogen}}$$

This formula is only roughly approximate, but is perhaps the best conversion formula yet devised.

The commonest method of measuring the work of a filter is by the percentage of purification obtained when the amount of some one of its constituents is compared in the crude sewage and the effluent. Dunbar and Thumm (1902) have attempted to justify this practice on theoretical grounds, claiming that percentage of purification, figured on oxygen consumed, runs parallel with keeping properties, irrespective of the original strength of the sewage. It may be assumed that some such general relation exists and that for a given process of purification on a given sewage it might be found with some degree of accuracy, but that the result is of general application to filters of all types and sewages of all kinds seems, in the absence of further evidence, improbable. Even though it may be true that a certain type of filter would produce a stable effluent by oxidizing one-half its organic matter, it does not necessarily follow that another type, working through characteristic and entirely different reactions, would produce the same result by the same percentage of oxidation. The amount of available oxygen in an effluent is also of importance in relation to its stability, and of two effluents showing exactly the same percentage of purification, one might be quite stable by virtue of its high nitrate and oxygen content and the other putrefactive owing to the absence of these substances. Such a difference is observed between effluents from a contact and a trickling filter. A contact filter running in a typical manner has already carried out during its cycle those secondary reactions by which oxygen and nitrates are used up for the oxidation of organic matter. Such an effluent is practically free from reserve oxygen and must for stability be purified to a much greater degree than would be the case with that from a trickling filter in which, by virtue of a reserve of oxygen, the oxidation may proceed after discharge.

The character of an effluent, with respect to its stable or putrescible character, is the thing of paramount importance. The effluent from a good sand filter will show so little organic matter and so high a nitrate value that there can scarcely be a moment's question about its quality after an inspection of the general analytical results. With the newer rapid processes of sewage treatment, however, effluents of such high purity are rarely obtained. In practice it is generally the aim to produce, not the best effluent possible, but merely one which can be discharged, under existing conditions, without creating a nuisance. Such a requirement may be fulfilled by an effluent containing considerable amounts of organic matter if two conditions be present: (1) A sufficient amount of reserve oxygen in the effluent to unite with all readily oxidizable organic matter and thus prevent the development of anaerobic conditions; and (2) a stability of the organic matter by virtue of which it does not readily undergo putrefactive decomposition. A measure of this quality of stability is the essential in judging of an effluent.

Endeavors have been made to develop a relation between the ordinary analytical data and the keeping qualities of an effluent. It must be confessed, however, that the determination of the oxygen consumed and of the various forms of nitrogen, while serving to identify undoubtedly good or bad effluents, fails to discriminate between a partially purified effluent which is perfectly stable and a similar one which is not. It is therefore necessary to fall back on a practical test of keeping quality as furnished by the incubator test. In this test, devised by Scudder (R. S. C., 1902 a) and since modified by others, the sample is bottled up and kept in the incubator at a warm summer temperature from three to five days. If at the end of that time it is still sweet and does not consume much more oxygen from permanganate than it did initially, it is pronounced a stable effluent.

In the tests at this station a modification of Scudder's method has been used. The sample, as in Scudder's work, was stored for five days at 37° and the oxygen consumed from permanganate was determined in the cold. In the Boston sewage and effluents, however, there are considerable amounts of readily oxidizable nonorganic materials, chiefly hydrogen sulphide. In order to exclude these substances the oxygen-consumed value was determined twice, once immediately on the addition of the permanganate and again after three minutes. The difference between the two results represents the true oxygen-consumed value. This method was suggested by Messrs. Johnson and Kimberly, of the Columbus experiment station.

The determination of total and suspended solids, which should form an integral part of every sewage analysis, was made for a considerable period. Unfortunately the enormously high chlorides in the Boston sewage, due to sea water, entirely masked the suspended solids when the determination was made in the ordinary way, and the direct determination of suspended solids by the Gooch crucible method was begun too late to get a large series of results. In the present paper, therefore, it is possible to report only, as an indirect measure of suspended solids, turbidity readings made with the Jackson turbidimeter (Jackson and Whipple, 1901), recalibrated for coarse material as described by Phelps (1905 a).

The determinations actually carried out on each sample in these experiments were as follows: Free and albuminoid ammonia, nitrates and nitrites, oxygen consumed and oxygen dissolved, turbidity, and odor. The albuminoid-ammonia and oxygen-consumed determinations were made on both the filtered and unfiltered samples. In addition to these regular determinations, an average sample was collected during the week, by adding each day to a bottle a definite amount of sewage sterilized with chloroform. On this average sample weekly determinations were made of chlorides, sulphates, iron, and alkalinity.

Analyses were made according to the methods generally employed in this part of the country, as described by Richards and Woodman (1904). Permanent standards have been used for the ammonia readings, as suggested by Jackson (1900). For the nitrite standards the Jackson permanent standards were used during a portion of the time, but it was soon found that a dilute solution of fuchsine, made up to match the desired nitrite reading by eye, gave a perfect standard as far as shade was concerned and was sufficiently permanent for all purposes. This is essentially the method since described by Westón (1905). Nitrates were determined by the Brucine method of Noll (1901), as described by Farnsteiner and his associates (1902).

For the oxygen-consumed determination the Kübel method was used, boiling for two minutes. In future work it is the intention to follow throughout the procedure outlined by the committee on standard methods of the American Public Health Association.

In tabulating the results of these experiments all ammonia, nitrite, and nitrate values are reported in terms of nitrogen, and all chemical results are expressed in parts per million. The dissolved oxygen is reported in this way rather than in the conventional form of per cent of saturation, since, while the latter method of expression may have had some significance in the study of surface waters, it has no value whatever in connection with sewage or filtration work in general. Owing to a change in the temperature of the water during treatment the results expressed in per cent of saturation may show an increase in the amount of oxygen, while in reality there is a marked decrease.

CHARACTER OF THE CRUDE SEWAGE.

During the two years of the operation of the sanitary research laboratory almost daily analyses of the crude sewage have been made. The sewage analyzed, as already explained, is a sample of the flow from 9 to 12 a. m. which has passed through the screen and grit chamber, drawn directly from the supply tank without any further chance for sedimentation or straining. The amount and character of the material previously removed from the grit chamber and supply tank are discussed on pages 115–116. Table LVI (p. 114) gives quarterly averages of the samples, taken, as a rule, on five days of each week. Yearly averages are also shown, the year being taken for convenience from June to June. Detailed studies of hourly and seasonal variations in the composition of the sewage have been previously reported (Winslow and Phelps, 1905).

The organic constituents of Boston sewage appear to be fairly normal in relation to one another. As stated above, regular determinations of the organic nitrogen were not made, but from the results of about fifty such determinations made at various times in the course of experimental work it may be stated that the average organic-nitrogen figure for the whole period would be about 20 parts per million. In this respect the sewage appears to be of about the same strength as the average sewage of Massachusetts cities, being slightly weaker than the sewages of Lawrence and Gardner (new system) and somewhat stronger than those of Framingham, Worcester, and Brockton.

The inorganic analyses of mixed weekly samples covering the calendar year 1904 showed an average of 2,300 parts per million of chlorine, 15 parts of iron, 125 parts of alkalinity, as calcium carbonate, and 220 parts of SO_3 as sulphates. The high chlorine and sulphate values are due to the large amount of sea water present in the sewage of Boston. If the chlorine normal to the sewage itself is assumed to be equal to the total nitrogen, as is commonly the case, a simple calculation shows

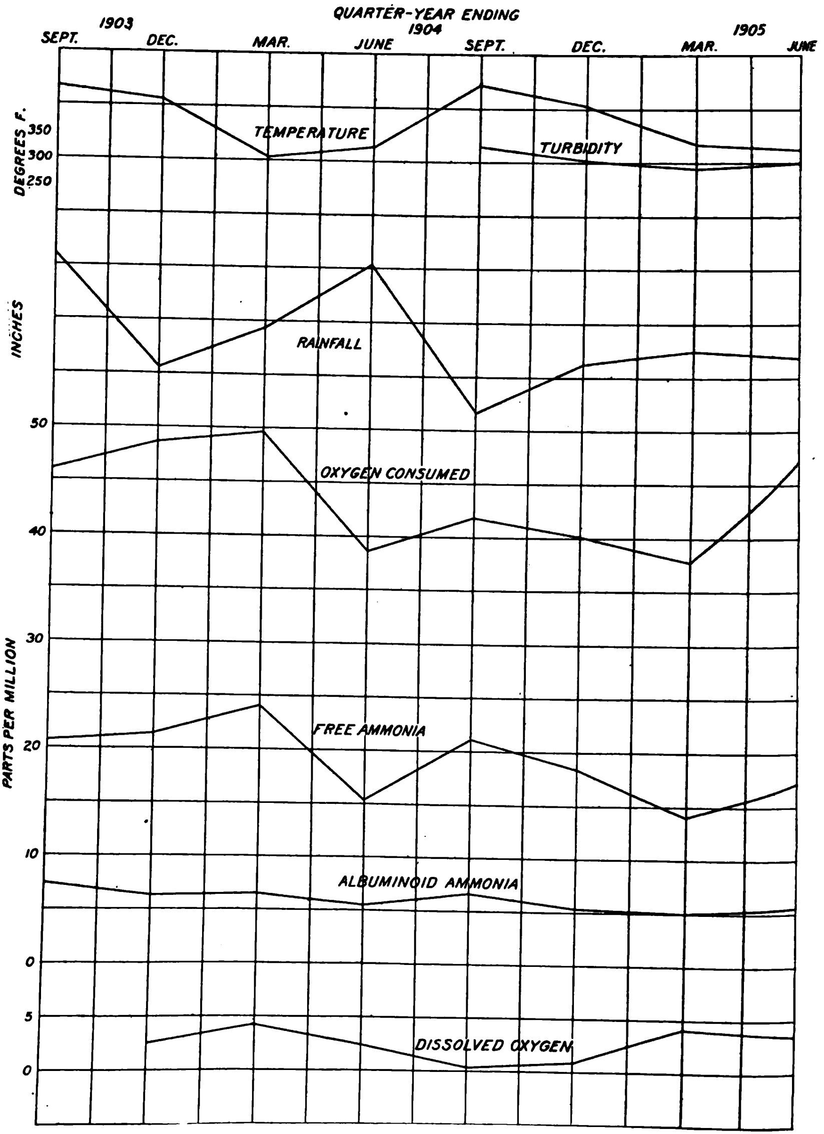

FIG. 15.—Composition of the crude sewage of Boston.

that the amount of chlorine present represents a volume of sea water equal to 11 per cent of the total volume of the sewage. This, however, is only an average value for the period. During each twelve hours the chlorine reaches a maximum figure of from 3,000 to 4,000 arts per million, representing 19 per cent of sea water, while between hese maxima there are minimum points of about 200 parts per milon, representing only 1 per cent of sea water. It may be an imporant question in any project for the purification of Boston's sewage hether the extra cost of pumping and of treating this sea water ight not be greater than the cost of keeping it out of the sewers. n the other hand, there is the possibility that this large amount of ea water, saturated as it is with oxygen, may be of actual advantage n any aerobic process of treatment.

With regard to the variations in strength at different periods, the irst point of importance to be noticed is the slight falling off in the trength of the sewage during the second year as compared with the irst. This effect may probably be attributed to the fact previously nentioned (p. 98) that on October 14, 1904, the sewage of the upper art of the drainage system was diverted to the new high-level sewer. Much of this upper drainage area is sewered on the separate system, nd ground water is in the main excluded. Furthermore, even with he combined system, the relative amounts of rain water entering the ewer is much greater in the city of Boston, with its great area of paved streets, than in smaller places with more open spaces and smaller relative amounts of pavement. It might also be possible, with the increasing per capita water consumption noticed in all cities from year to year and amounting in the metropolitan water district to 2 or 3 per cent per annum, that there would be a resulting decrease in the strength of the sewage. On the other hand, the low rainfall during 1905 must have operated in an opposite direction.

The quarterly variations in the strength of the sewage are considerable, and, as is shown on pages 122–123, markedly influence the effluents of the various purifying processes. The controlling cause in these seasonal variations is the rainfall. The first effect of a shower is to increase the oxygen consumed by the introduction of street washings. A long period of rain, however, has the opposite result. The general rule, as has been stated elsewhere (Winslow and Phelps, 1905), is that sewage is weakest in spring and summer. The precipitation was unusually low in the summer of 1904 and the spring of 1905, and therefore the seasonal relations for the second year are somewhat abnormal.

TABLE LVI.—*Composition of Boston sewage (quarterly averages), 1903–1905.*

Date.	Number of samples.	Temperature (° F.).	Analyses (parts per million).									
			Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
				Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
				Total.	In solution.	In suspension.				Total.	Soluble.	
June to August, 1903	27	67	.....	7.4	3.4	4	20.7	0.11	0.1	46	......	
September to November, 1903	42	62	.....	6.2	3.1	3.1	21.3	.41	0	48.7	......	2.4
December, 1903, to February, 1904.	10	51	.....	6.6	3.6	3	24	.42	0	49.6	......	4.2
March to May, 1904	32	55	.....	5.4	2.7	2.7	15.3	.14	0	38.7	22.5	2.1
June to August, 1904	47	69	330	6.7	3	3.7	21	.16	.2	41.9	23.7	.3
September to November, 1904	33	61	300	5.4	2.6	2.8	18.4	.22	.4	40.2	22.2	.9
December, 1904, to February, 1905.	44	47	300	5	3.1	1.9	14	.10	.2	38.6	25.7	4.2
March to May, 1905	35	45	300	5.6	3.1	2.5	17.2	.08	0	47.4	27.3	3.5
June, 1903, to June, 1904[a]	102	60	.....	6.3	3.1	3.2	19.7	.27	.1	45.2	22.5	2.5
June, 1904, to June, 1905[a]	153	58	305	5.7	3	2.7	17.6	.14	.1	41.5	24.6	2.2
June, 1903, to June, 1905[a]	255	59	305	5.9	3	2.9	18.5	.19	.1	43.1	23.8	2

[a] Yearly and biyearly averages given in this and subsequent tables are obtained by averaging the daily results and are therefore not averages of the quarterly figures given.

REMOVAL OF SUSPENDED MATTER.

In any discussion of the solids in sewage it is necessary to distinguish clearly between three classes of suspended matter. In the first place, there are generally present large floating objects, such as rags, paper, sticks, and other gross débris. Before pumping sewage it is customary to pass it through screens for the separation of such material, which may therefore be denoted as screenings. Another class of matter, present especially in sewage which includes street washings, consists of sand and other heavy mineral particles, sharply distinguished from the ordinary sewage sludge by the rapidity with which they settle out when the sewage is brought either to complete rest or to a low velocity of flow. Chambers or tanks for the removal of such material are commonly called grit chambers or detritus tanks, and the material may be conveniently spoken of as detritus. After the removal of the screenings and the detritus there remains in suspension the sewage sludge proper, composed of finely divided matter largely organic in nature which settles out only at a low velocity, and then but slowly.

As a rule it is found desirable to screen sewage which is to be pumped and to settle sewage which has to pass through an inverted siphon, as is the case with that of the south metropolitan district. Where any purification is to be carried out both these preliminary treatments are generally advisable. The amount of solid material removed is often considerable. At Manchester, England, during 1904, the amount of combined screenings and detritus amounted to about 4,000 tons from a total of 13 billion gallons of sewage, or about 7,000 pounds per million gallons (Manchester, 1904). At Boston during

1903 about 10,000 cubic yards of detritus were removed from the settling chamber at the Dorchester pumping station from a total volume of sewage of 32 billion gallons, an average of about 0.31 cubic yard per million gallons. The composition of this detritus is not known, but a fair estimate would be 60 per cent of water and a solid content of 1½ tons per yard, making 900 pounds per million gallons of sewage (Boston, 1904). The amount of screenings removed during 1897 was recorded and found to be about 1,000 cubic yards, or, roughly, 500 tons, an average of 300 pounds per million gallons of sewage (Boston, 1898).

In the experiments at this station, as noted above, screenings and detritus were taken out by a grit chamber and to a slight extent by supply tank A. During the actual time of pumping the pump discharges on an average about 1,000 gallons per hour, which produces a velocity of 1.1 feet per second in the 2½-inch suction pipe. The velocity is checked in the grit chamber, being reduced to an average of 0.04 foot per second, and the time occupied in passing the grit chamber is about forty-five seconds. Since March, 1904, when the grit chamber was installed, a careful record of the amount of sediment removed has been kept, the whole amount carefully sampled, and an aliquot portion preserved for analysis. A small amount of material removed from supply tank A has also been weighed and sampled and mixed with the grit chamber material in proportionate parts.

The amount of detritus removed by the grit chamber amounted in sixteen months to 4,800 pounds, or 2.4 cubic yards, of wet material from a total volume of sewage equal to a little over 3 million gallons—1,600 pounds, or 0.65 cubic yard per million gallons. All the material thus removed was carefully sampled and its moisture determined. A portion of each dried sample was preserved and mixed with proportionate parts of later samples, and the mixture was finally analyzed. A certain portion of each sample, consisting largely of clean stone, was not included in the analysis. The amount of moisture, the proportions of clean stone and of dry detritus, and the analysis of the latter are shown in Table LVII, first in total amounts and then in parts per million of the total volume of sewage (3 million gallons).

TABLE LVII.—*Amount and composition of detritus removed from grit chamber from March 26, 1904, to June 1, 1905.*

	Wet detritus.	Water.	Clean stone, etc.	Fine, dry detritus.			
				Total.	Loss on ignition.	Organic nitrogen.	Organic carbon by permanganate.
Total pounds	4,800	1,300	570	2,900	319	6.6	5.1
Pounds per million gallons of sewage	1,600	430	190	970	106	2.2	1.7
Parts per million parts of sewage	190	52	23	117	13	.26	.2

As the analysis indicates, this material is not sludge in any sense of the word. It is for the most part clean sand mixed with a considerable amount of coal cinders and small bits of wood, cloth, and pebbles. During the whole period it has been spread upon the grounds of the station immediately surrounding the laboratory and has given no offense.

The figures show only the total and average amounts of detritus collected for the whole period. No accurate data are at hand to show the effect of the seasons on the amount of detritus deposited It may be judged by the frequency with which it was necessary to clean out the chamber that the maximum deposits occurred during the early spring thaws. The Boston city records, already referred to, show that at Moon Island there is a maximum of deposit in March and a second maximum during the summer months. Local conditions of rainfall evidently largely determine the amount of detritus sent into the sewer, but monthly variations from the mean yearly deposit are not as a rule greater than 25 per cent of that value. In the spring of 1904 a large amount of snow was thawed by the warm rains and during ten days 1,600 pounds of detritus were taken from the detritus chamber and from storage tank A, into which some excess of detritus had been carried over; this was about one-third of the total amount removed during the fifteen months of the experiment. The amount of sewage pumped during that time was 100,000 gallons, giving an average of 16,000 pounds of detritus per million gallons of sewage. This may be fairly taken as the maximum for a like period of time, although for shorter periods the rate of deposit might be greater.

The line of demarcation between the so-called detritus and the remaining suspended solids, or sewage sludge proper, is rather sharply marked by the rapidity with which the particles settle. One class of material will settle out in a very few minutes when the velocity is still considerable and the other will settle only when the liquid is practically at rest and in the course of hours rather than minutes. According to figures given by Robinson (1896), a velocity of 0.5 foot per second will not move fine clay and 0.7 foot will just move coarse sand. Hence it may be stated that detritus may be removed from sewage at any velocity less than the former figure. On the other hand, sedimentation of the true suspended sludge necessitates a slackening of velocity to 0.1 foot per second or less. In the London settling basins velocities of 0.07 foot are maintained; at Manchester, 0.05; at Saltley and Sutton, 0.03; and at Frankfurt a. M., 0.01 to 0.02. Steurnagel (1904) found that velocities less than 0.07 foot permitted as complete sedimentation as was possible with absolute rest, but that 0.13 foot was too great. Again, the time required for sedimentation is considerably different in these two classes of material. Detritus, being largely sand, will settle out in a very few minutes; but the remaining solids require a much longer time for sedimentation. In some experiments on this point in a 40-cm. cylinder the removal of suspended solids by sedimentation was found to be about 25 per cent in five minutes, 50 per cent in thirty minutes, and 75 per cent in twenty-four hours. Steurnagel studied the same phenomenon in a deeper layer (2 meters) and found the removal of suspended organic matter to be 42 per cent in five minutes, 61 per cent in twenty-five minutes, 75 per cent in six hours, and 80 per cent in twenty-four hours.

Whether the suspended organic solids in sewage must be removed by some special process depends largely on the general method of purification. With intermittent filters, if there be ample areas of sand available, crude sewage may be handled without preliminary treatment, as is the case at most of the Massachusetts areas. When, on the other hand, suitable sand is difficult to obtain, it may be advisable to remove the suspended solids as far as possible in order to obtain more rapid rates. With the contact filter it seems probable that some method of sludge removal will be generally necessary in order to maintain the capacity of the beds. With the trickling filter it may often be possible to handle crude sewage without preliminary treatment. If a clear, as well as a nitrified, effluent is desired, however, sedimentation must follow the oxidizing process. Whether the removal of solids should precede or follow filtration in this case must be determined by experiment.

If the organic suspended solids are to be removed from sewage, there is a choice of three different methods—namely, sedimentation, chemical precipitation, and straining. For a comparison of the three methods, experiments at Lawrence furnish some useful data. Table LVIII has been compiled from the annual reports of the Massachusetts State board of health for the years 1893–1903.

TABLE LVIII.—*Effect of various processes of preliminary sewage treatment at Lawrence, Mass. (Massachusetts, 1894–1904).*

[Parts per million.]

Process and material.	Date.	Nitrogen as—				Oxygen consumed in 2 minutes' boiling.
		Albuminoid ammonia.			Free ammonia.	
		Total.	In solution.	In suspension.		
Alum precipitation:						
Sewage	1893–1897	6.3	2.6	3.7	29.7	40.3
Effluent		2.8	2	.8	30.7	20.9
Hard-coal strainer:						
Sewage	1901–1903	5.5	2.9	2.6	42.1	38.1
Effluent		3	2.1	.9	43.3	23.6
Coke strainer:						
Sewage	June, 1894, to September, 1898.	6.4	2.5	3.9	30.8	38.8
Effluent		3.3	2.3	1	31.8	22.2
Septic tank A:						
Sewage	1901–1903	6.4	2.9	3.5	39.1	47.7
Effluent		3.3	2.1	1.2	36.7	29.4
Sedimentation:						
Sewage	1893–1897	6.3	2.6	3.7	29.7	40.3
Effluent		4.2	2.7	1.5	33	30.7

The samples of effluent from chemical precipitation with alum represent the supernatant liquor obtained by treating the sewage with sulphate of alumina at a rate of 1,000 pounds per million gallons and allowing the mixture to settle for four hours in a barrel. The sedimentation experiments were made by settling the sewage for four hours without other treatment. The coke strainer was a layer of coke breeze 6 to 8 inches deep and was operated at a rate of about 1 million gallons per acre per day. The coal strainer was a 12-inch layer of "buckwheat" coal and was run at a rate of approximately 1 million gallons per acre per day. Some septic-tank results for 1900–1903 have been included, the septic tank being considered in this place as a variant of sedimentation. The important conclusion from these experiments is that the results of the various processes are not very dissimilar. The small differences observed are in favor of the chemical-precipitation process, plain sedimentation showing the poorest results.

Martin (1905) has compiled, from the testimony given before the royal sewage commission, figures from various sources relating to the removal of suspended solids by chemical precipitation, septic tanks, and coarse filters. While the coarse filter is not strictly a preliminary treatment for the removal of suspended solids, since it is also a true process of purification, the comparative results obtained by these three processes are of interest in this connection. The average suspended solids in effluents from chemical precipitation plants are, at Kingston 14 parts per million, at Chorley and Richmond from 40 to 70, and at London 112. Similar figures from septic-tank installations are, at Salford 29 to 71, Manchester 100 to 286, Leeds 114 to 143, Burnley 130, Oldham 143, Sheffield 157, Accrington 178, and Birmingham 244. The average suspended solids in coarse-bed effluents are at Sheffield 43 to 57, Sutton 45, Blackburn 60, Aylesbury 111, and Leeds 151 to 196.

In general it is clear that chemical precipitation and straining will produce effluents which as regards suspended solids only are somewhat superior to those from either plain sedimentation or septic treatment. In the case of precipitation the cost of the chemical treatment and the necessary disposal of an increased volume of sludge must be considered. In straining processes sludge is produced in varying quantity according to the conditions under which the strainer is operated. A strainer run at so low a rate that anaerobic processes are carried out within it is practically a septic tank and can be so operated that there is little accumulation of organic matter. Such a strainer is septic tank No. 6 at this station, described on page 124, where it is pointed out that here the tank operates like a simple septic tank, the stone filling playing no important part. Again, with still lower rates and ith resting periods, the strainer becomes practically an oxidizing lter and disposes of considerable sludge in much the same way as does contact bed. On the other hand, true strainers, run at rapid rates ith the object simply to remove suspended solids without destroying hem, come in a different class. Their surfaces require constant care, hile not only the accumulated sludge itself but that part of the surace which is necessarily removed at the same time must be disposed f. Sedimentation, although it does not give quite such perfect emoval, is generally preferable to either of these methods, since it voids the expense of chemicals and of renewing or treating the surace of strainer beds; it will probably prove in general the most pracical and economical process of preliminary treatment for removing ine suspended material.

Under the term sedimentation is included septic treatment, since the septic process is really plain sedimentation with the additional anaerobic fermentation of the sludge produced. Such a process seems to combine the best features of all the preliminary treatments thus far proposed, since it effects an adequate removal of suspended solids with no expense for chemicals and produces a minimum of sludge. Furthermore, the actual removal of suspended solids is somewhat greater with the septic tank than with plain sedimentation, from the solution of particles too small to settle easily. The only disadvantage in septic treatment is that if it be too prolonged changes may be set up which make subsequent treatment difficult. The problem is to combine the maximum liquefying action with the minimum production of toxic substances. If that can be done, the septic tank offers in general the best solution of the problem.

PRELIMINARY TREATMENT IN THE SEPTIC TANK.

It having been assumed that if any preliminary treatment were necessary in the purification of Boston sewage the septic tank would probably furnish the most available method, the next problem was to determine the best conditions under which a septic tank could be operated. In particular, it was desired to compare the efficiency of different periods of storage, the results obtained from open and closed tanks, and the effect of filling a tank with stone in order to increase the amount of surface action.

Tanks Nos. 5, 6, 8, and 10, all closed tanks, were started in June, 1903, and open tanks Nos. 7 and 9 in March, 1904. All were operated continuously until June, 1905. Tank No. 5 was operated for the first six months at a forty-eight hour rate and for the remaining eighteen months at a twelve-hour rate. Tank No. 7 had a twelve-hour period, tanks Nos. 6, 9, and 10 a twenty-four hour period, and tank No. 8 a forty-eight hour period. In each case the linear distance traveled was about 6 feet and the depth 3 feet, making the

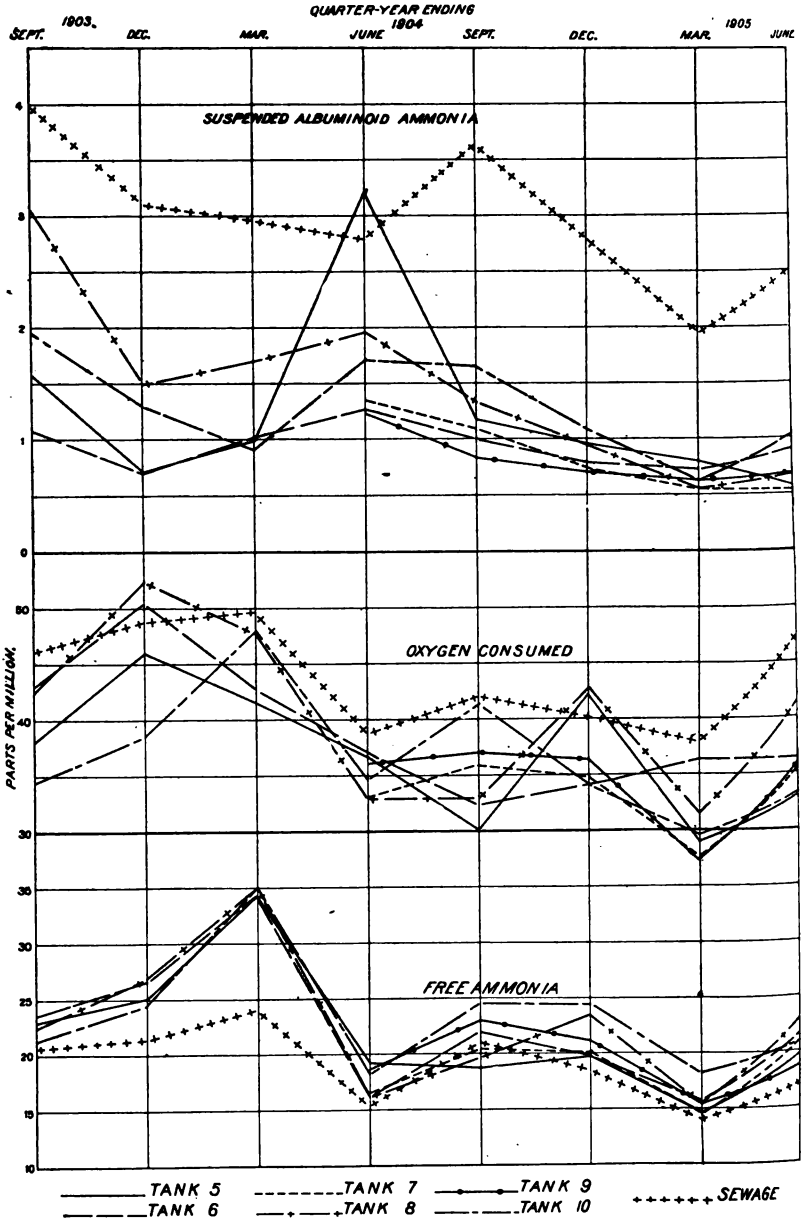

FIG. 16.—Composition of septic effluents.

ratio of l:d equal 2:1. The importance of this factor has recently been pointed out by Hazen (1904). Tank No. 6 was filled with

1½-inch crushed stone. Septic action began in all the tanks very soon after they were started, the effluent being free from gross turbidity and much darkened. The dark color and offensive odor of these septic effluents are undoubtedly due in part to the formation of sulphides from the large amount of sulphates introduced with the sea water. This phenomenon has been noticed by Clark in the treatment of hard waters at Lawrence (Barbour, 1904). Hoppe-Seyler (1886) believed the reaction to be a direct reduction of calcium sulphate by methane. It is of some importance, aside from the foul odors produced, since it has been found at Burton-upon-Trent that the formation of H_2S has a serious effect on subsequent purification on land (Smith, 1901). Scum formed at first on the open tanks, but later disintegrated and sank and did not re-form. In the closed tanks a scum 1 inch thick was found when they were finally opened.

The most important constituents of the effluents from the various tanks are plotted in fig. 16. It will be noticed in the first place that the various effluents are much alike in composition. All show a general improvement during the course of the two years, but this is accounted for rather by the decreasing strength of the sewage than by increased efficiency. The septic-effluent curves follow the crude sewage closely all through, rising in the late autumn of 1903, in the summer of 1904, and in the spring of 1905, when the sewage strengthened with diminishing rainfall. In absolute values, oxygen consumed shows a slight decrease in the septic tanks and free ammonia a slight increase. No doubt the reduction in carbonaceous matter is really considerably greater than it appears, since the septic decomposition tends to break up the more stable compounds and increases that proportion of the total carbonaceous matter which is revealed by the oxygen-consumed test. The hydrogen sulphide also interferes seriously with the value of this test. The chief difference between the sewage and septic effluents, aside from the reduction in turbidity, appears in the albuminoid ammonia. The nitrogen in this form was diminished to from two-thirds to one-half its sewage value. The diminution of dissolved albuminoid ammonia was slight but distinct, while the suspended portion was reduced to a little over one-third its original amount. The suspended albuminoid ammonia is plotted with the total oxygen consumed and free ammonia in fig. 16.

TABLE LIX.—*Quarterly averages of analyses of effluent from septic tanks.*

Date.	Temperature (° F.).	Turbidity.	Analyses (parts per million).					
			Nitrogen as—				Oxygen consumed.	
			Albuminoid ammonia.			Free ammonia.	Total.	Dissolved.
			Total.	In solution.	In suspension.			
TANK 5, CLOSED TANK; STORAGE PERIOD, TWELVE HOURS.[a]								
1903-4.								
June to August	68	....	4.2	2	1.6	22.9	38	....
September to November	59	....	3.1	2.4	.7	25	45.9	....
December to February	48	....	3.9	2.9	1	34.2	41.3	....
March to May	52	240	6	2.8	3.2	19	36.5	26.5
Yearly average	58	240	4.1	2.6	1.5	24.3	41.7	26.5
1904-5.								
June to August	67	220	3.8	2.7	1.1	18.7	30.1	23.8
September to November	57	190	3.6	2.6	1	19.6	42.1	34.3
December to February	44	190	3.6	2.8	.8	14.6	28.9	22.9
March to May	46	200	3.2	2.6	.6	19.7	33	28.1
Yearly average	56	200	3.6	2.7	.9	18.1	33.2	26.9
General average	57	200	3.8	2.6	1.2	20.7	36.9	26.9
TANK 6, CLOSED SEPTIC TANK FILLED WITH STONE; STORAGE PERIOD, TWENTY-FOUR HOURS.								
1903-4.								
June to August	68	....	3.7	2.6	1.1	23.5	42.8	....
September to November	59	....	2.9	2.2	.7	26.5	50.3	....
December to February	47	....	3.6	2.6	1	34.2	42.7	....
March to May	52	180	4.1	2.9	1.2	16	37	26.2
Yearly average	58	180	3.4	2.5	.9	24.3	44.9	26.2
1904-5.								
June to August	67	170	3.2	2.2	1	21.9	32.4	27.2
September to November	59	190	3.3	2.5	.8	19.6	34	29.7
December to February	44	190	3.9	3.2	.7	15.7	29.6	22.8
March to May	46	160	3.3	2.4	.9	20.8	33.3	24.7
Yearly average	54	180	3.4	2.6	.8	19.5	32.2	26
General average	57	180	3.4	2.5	.9	21.5	37.8	26
TANK 7, OPEN SEPTIC TANK; STORAGE PERIOD, TWELVE HOURS.								
1904-5.								
March to May	52	170	3.9	2.5	1.4	16.5	33.1	26.5
June to August	69	160	2.8	1.7	1.1	20.3	35.8	31.4
September to November	54	170	3.1	2.3	.8	20.1	34.9	31.7
December to February	45	180	3.5	3	.5	14.5	27.7	21.4
March to May	46	190	3.7	3.1	.6	16.8	35.5	29
Yearly average, June to June	56	170	3.2	2.5	.7	17.9	33.2	28.1
General average	55	170	3.4	2.5	.9	17.6	33.2	27.9
TANK 8, CLOSED SEPTIC TANK; STORAGE PERIOD, FORTY-EIGHT HOURS.								
1903-4.								
June to August	66	....	5.6	2.5	3.1	22.4	42.4	....
September to November	58	....	3.6	2.1	1.5	26.8	52.3	....
December to February	47	....	5	3.3	1.7	35	47.7	....
March to May	51	230	4.3	2.3	2	16.1	32.8	26.5
Yearly average	57	230	4.3	2.4	1.9	25.1	46.1	26.5
1904-5.								
June to August	67	200	3.7	2.3	1.4	19.5	32.9	26.3
September to November	38	210	3.5	2.5	1	23.5	42.9	35.6
December to February	45	180	3.7	3.1	.6	15.3	31.6	25.1
March to May	45	170	3.5	2.8	.7	23	41.6	33.8
Yearly average	56	190	3.6	2.7	.9	20.5	37.3	30.3
General average	57	190	3.8	2.6	1.2	22.1	40.7	29.9

[a] Before Dec. 7, 1903, 48 hours.

TABLE LIX.—*Quarterly averages of analyses of effluent from septic tanks*—Continued.

TANK 9, OPEN SEPTIC TANK; STORAGE PERIOD, TWENTY-FOUR HOURS.

Date.	Temperature (° F.).	Turbidity.	Analyses (parts per million).					
			Nitrogen as—				Oxygen consumed.	
			Albuminoid ammonia.			Free ammonia.	Total.	Dissolved.
			Total.	In solution.	In suspension.			
1904–5.								
rch to May	52	170	3.6	2.4	1.2	18.6	36	26.6
ne to August	68	160	2.7	1.8	.9	22.9	36.9	29.1
ptember to November	55	170	2.9	2.2	.7	21.2	36.3	32.1
cember to February	45	190	3.6	2.9	.7	15.3	27.3	21.9
rch to May	46	160	3.9	3.2	.7	18.8	36	29.8
Yearly average, June to June	56	170	3.2	2.4	.8	19.6	33.7	27.7
General average	55	170	3.2	2.4	.8	19.4	34.1	27.5

TANK 10, CLOSED SEPTIC TANK; STORAGE PERIOD, TWENTY-FOUR HOURS.

Date.	Temperature (° F.).	Turbidity.	Albuminoid ammonia Total.	In solution.	In suspension.	Free ammonia.	Oxygen consumed Total.	Dissolved.
1903–4.								
ne to August	66	....	4.5	2.6	1.9	21.3	34.3	....
ptember to November	58	....	3.4	2.1	1.3	24.3	38.5	....
ecember to February	49	....	3.8	2.9	.9	35	48	....
arch to May	51	270	4.2	2.4	1.8	18.2	34.6	26.4
Yearly average	57	270	3.8	2.4	1.4	23.4	37.9	26.4
1904–5.								
ne to August	67	190	3.5	1.9	1.6	24.6	41.3	23.2
ptember to November	57	220	3.9	2.8	1.1	24.4	34	23
ecember to February	43	250	3.9	3.2	.7	18.1	36.3	23.6
arch to May	45	170	3.7	2.7	1	20.8	36.3	27.5
Yearly average	56	210	3.7	2.6	1.1	21.9	37.3	24.1
General average	56	210	3.8	2.5	1.3	22.5	37.5	24.5

TABLE LX.—*General averages of analyses of crude sewage and septic effluents.*

Material.	Date.	Storage period (hrs.).	Temperature (°F.).	Turbidity.	Analyses (parts per million).					
					Nitrogen as—				Oxygen consumed.	
					Albuminoid ammonia.			Free ammonia.	Total.	Soluble.
					Total.	In solution.	In suspension.			
ewage	June, 1903, to June, 1905.	....	59	305	5.9	3	2.9	18.5	43.1	24.4
Do	March, 1904, to June, 1905.	....	58	305	5.7	3	2.7	17.6	41.5	24.7
ffluent from tank No. 5	June, 1903, to June, 1905.	[a]48–12	57	200	3.8	2.6	1.2	20.7	36.9	26.9
ffluent from tank No. 6	.....do........	24	57	175	3.4	2.5	.9	21.5	37.8	26
ffluent from tank No. 7	March, 1904, to June, 1905.	12	55	170	3.4	2.5	.9	17.6	33.2	27.9
Effluent from tank No. 8	June, 1903, to June, 1905.	48	57	190	3.8	2.6	1.2	22.1	40.7	29.9
Effluent from tank No. 9	March, 1904, to June, 1905.	24	55	170	3.2	2.4	.8	19.4	34.1	27.5
Effluent from tank No. 10	June, 1903, to June, 1905.	24	56	210	3.8	2.5	1.3	22.5	37.5	24.5

[a] Changed Dec. 7, 1903, from 48 hours to 12 hours.

The average analyses of the effluent from each tank for the whole period of operation, with the average analyses of the sewage for the fifteen-month and the two-year periods, are indicated in Table LX. The figures on the whole show a remarkable uniformity of results for open and closed tanks and for twelve, twenty-four, and forty-eight hour periods. Even the figures for suspended albuminoid ammonia and total oxygen consumed bring out only slight differences. In a comparison of tanks Nos. 5 and 10 (closed) with the corresponding twelve and twenty-four hour open tanks, the open-tank effluents appear to be slightly better. It must be remembered, however, that the open tanks were operated during the last fifteen months only, when the sewage was weaker. This factor being taken into account, the work of the open and closed tanks is practically equal.

With regard to period the figures are no more conclusive. A comparison of tanks Nos. 7 and 9 (open) apparently shows no important difference between the effect of twelve and of twenty-four hours' storage. Similarly, tanks Nos. 5, 8, and 10 (closed) produce almost the same results, although operating with periods varying from twelve to forty-eight hours. Tank No. 6, filled with 1½-inch crushed stone, produces a somewhat greater reduction in suspended albuminoid ammonia than do the other tanks, but the difference is too slight to be of practical importance.

TABLE LXI.—*Analyses of septic-tank contents, including sludge and scum, at close of experiment.*

No. of tank.	Date.	Storage period (hrs.).	Depth of sludge (in.).	Analyses (parts per million).								
				Solids.		Nitrogen as—				Oxygen consumed.		Fats.
				To-tal.	Loss on igni-tion.	Free am-mo-nia.	Albumi-noid am-monia.		To-tal.	Total.	Sol-uble.	
							To-tal.	Sol-uble.				
5......	June, 1903, to June, 1905.	ᵃ48-12	8.4	17,000	6,580	35	145	10	425	1,000	130	1,590
6......	.....do............	24	......	....	....	6	66	10	......	640	48	3,000
7......	March, 1904, to June, 1905.	12	3.3	10,600	3,040	34	42	10	250	680	100	620
8......	June, 1903, to June, 1905.	48	8.7	14,900	6,068	50	80	10	400	940	110	870
9......	March, 1904, to June, 1905.	24	4.4	12,500	3,912	40	70	7	325	680	110	1,090
10.....	June, 1903, to June, 1905.	24	5.4	16,900	5,952	50	102	7	400	1,020	100	900

[a] Changed Dec. 7, 1903, from 48 hours to 12 hours.

When this series of experiments was closed in June, 1905, the inlet and outlet of each tank were closed and the contents, including scum and sludge, were thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the material which had accumulated during the whole period of operation. The results are shown in Table LXI. The analyses refer to the total quid and solid contents of the tank at the time its operation ceased, suspension containing about 98 per cent of water. The sludge was stimated by allowing the mixed tank contents to settle in a cylinder r twenty-four hours and observing the relation between the hick sediment produced and the clear supernatant liquid. The hickness of the sludge (which as measured by this method includes he scum also) was 3.3 and 4.4 inches for the tanks which had run for fteen months and 5.4, 8.4, and 8.7 inches for those which had run for wo years. With regard to total solids the loss on ignition is impor-ant and measures fairly the total storage of organic matter by the eptic tank. This is seen to be from 3,000 to 4,000 parts per million fter fifteen months and about 6,000 parts after two years. The effect f the storage period on the accumulation of sludge is striking. As lready shown, the tanks in which the flow was more rapid appear to xercise quite as much purifying power as the slower ones. Since wice as much sewage passed through tank No. 7 as through tank No. and twice as much through tank No. 10 as through tank No. 8, with he production of a comparable effluent, more sludge might be expected n tanks Nos. 7 and 10. We actually find less, which suggests that the ecomposing action of the tank is favored by a shorter storage period. n tank No. 7, with a twelve-hour period, there were 3.3 inches of ludge, corresponding to 0.6 cubic yard per million gallons of sewage assed. In tanks Nos. 5, 9, and 10, with a twenty-four-hour period, he depth of sludge was respectively 8.4, 4.4, and 5.4 inches, equiv-lent to 1.4, 1.7, and 1.5 cubic yards per million gallons. In tank No. , with a forty-eight hour period, there were 8.7 inches of sludge, or .7 cubic yards per million gallons.

It has been pointed out above that a prolonged septic action diminishes the number of bacteria and probably interferes with sludge reduction. Another interesting suggestion, which may help to explain the results herein recorded, has recently been made by Stoddart (1905). He finds, in a septic tank of several compartments, a considerable deposit of sludge in the first compartment, giving a fairly clear supernatant liquid, which in the last chamber of all undergoes a secondary decomposition, leading to the throwing down of an additional precipitate of offensive sludge.

From the data in Tables LX and LXI have been calculated, in Table LXII, the actual amounts of certain constituents, which were (*a*) allowed to enter the tanks, (*b*) discharged in the effluents, (*c*) stored in the tanks as sludge and scum, and (*d*) removed by septic decomposition. About 50 pounds of nitrogen as albuminoid ammonia per million gallons of sewage entered the tanks. Roughly, 30 pounds were discharged and 20 pounds remained behind, of which 15 to 17 pounds were decomposed. The last columns in the table show the total volatile solids and fats stored in the various tanks, calculated in relation to the sewage treated. These figures bring out very sharply the superior decomposing power of the tanks operated at short periods. Tank No. 7 (twelve hours) and tank No. 5 (twelve hours for the last eighteen months) exhibit the lowest values. Tanks Nos. 9 and 10 (twenty-four-hour period) come next, with 90 and 101 pounds, respectively. Tank No. 8, with its forty-eight-hour storage, gave 206 pounds of stored organic matter per million gallons of sewage treated. The large proportion of fats shown in the last column is notable, amounting to one-fourth or one-eighth of the total stored organic matter.

TABLE LXII.—*Storage and decomposition of organic matter in septic tanks.*

No. of tank.	Flow (gallons).	Storage period (hours).	Nitrogen as albuminoid ammonia.				Solids stored.		Fats stored.
			Entering. (*a.*)	Leaving (*b.*)	Stored. (*c.*)	Decomposed. (*d*=*a*−*b*−*c.*)	Total.	Loss on ignition.	
			Pounds per million gallons of sewage passed.						
5	445,000	[a] 48–12	49.2	31.7	1.3	16.9	178	69	16
6	135,000	24	49.2	28.3	[b] 10.1	11.9	....	....	101
7	393,000	12	46.7	28.3	.4	18.1	115	35	6
8	133,000	48	49.2	31.7	2.6	15.9	510	206	29
9	197,000	24	46.7	26.7	1.5	17.8	279	90	25
10	266,000	24	49.2	31.7	1.6	17.3	282	101	15

[a] Changed December 7, 1903, from 48 hours to 12 hours.

[b] Estimated from loss of capacity in tank due to sludging up of the space between the stones and from analysis of a sample of the sludge.

Altogether it may be concluded from these experiments that the septic tank will effect a considerable removal of solids from Boston sewage, amounting to about two-fifths of the nitrogen as measured by albuminoid ammonia. Its effluent is free from gross turbidity, but dark and offensive from the liberation of hydrogen sulphide. Of the organic matter retained in the tank, a very large proportion, amounting to well over three-fourths if measured by the albuminoid nitrogen, is decomposed, and the accumulation of stored material in the tank is slight after two years of operation. Apparently such tanks might operate for several years without being cleaned. The covering of tanks is nonessential, since closed and open tanks work equally well. Storage periods varying from twelve to forty-eight hours give similar effluents, but there is an increasing tendency to accumulate sludge as the period is lengthened. The filling of a septic tank with stone is of only slight advantage.

It is believed, therefore, that open tanks with a capacity not exceeding the flow for twelve hours would prove the most favorable preliminary treatment for Boston sewage.

PURIFICATION BY INTERMITTENT SAND FILTRATION.

The early Lawrence experiments indicated pretty clearly what may be effected by intermittent sand filters operating under the most favorable conditions. They showed that a 4 to 5 foot bed of sand of an effective size of 0.04 to 1.4 mm. would take sewage at rates varying from 0.02 to 0.06 million gallons per acre per day, producing a clear and odorless effluent in which the nitrogenous constituents had been almost entirely converted into the mineral form. In the line of a modification of the process in order to secure more rapid rates than these the only important step has been the installation of preliminary septic tanks, and septic effluent has been treated in the Middle West at rates up to 0.4. Exact data are scarce, however, as to the comparative operation of sand filters with crude sewage and with septic effluent. It was therefore planned, in this investigation, to determine how far the preliminary septic process would be of advantage in the treatment of Boston sewage, and—with or without its use—to what extent the required area of sand could be diminished by the use of rates of filtration over 0.1 million gallons per acre per day. It was desired also to find out how far the depth of sand could be decreased with safety, since this may be an important economic consideration when artificial sand areas must be constructed.

The first sand filters, Nos. 1 and 2, began operation in June, 1903. Both were cypress tanks, 6 by 4 feet by 3 feet deep, underdrained with 6 inches of material ranging from 3-inch stones up to the sand. No. 1 contained, over the underdrain material, two feet, and No. 2 one foot of drift sand with an effective size of 0.17 mm. and a uniformity coefficient of 3.5. Both were started at a rate of 0.1 and so operated until December, 1903. At that time the rate on No. 1 was doubled, while that of No. 2 remained the same in amount but was divided into two daily doses with twelve hours' interval between them. In June, 1904, both rates were doubled, No. 2 receiving 0.2 million gallons per acre per day in two doses and No. 1 receiving 0.4 million gallons per day in four doses. Both filters received crude sewage.

This experiment gave conclusive results as to the minimum depth for a sand filter. While the 2-foot filter worked satisfactorily, No. 2, with half that depth, was a failure. Its effluent was dark and turbid and of an offensive odor. Not one of the samples tested passed the incubator test. The analytical results in Table LXIII show marked variations from time to time, but the free ammonia present was generally from 15 to 20 parts per million—nearly as high a value as that of the crude sewage. The albuminoid ammonia was usually between 2 and 3 parts and the oxygen consumed about 20 parts—in each case about half the sewage value. Nitrates were always low.

The operation of the 2-foot bed, on the other hand, was eminently satisfactory. The effluent was clear and bright and entirely free from turbidity and odor. Every sample tested successfully passed the incubator test and even bacteriologically the effluent appeared well, having an average of 1,220 bacteria per cubic centimeter. The bacterial composition of the various effluents obtained in these experiments has been fully discussed elsewhere (Winslow, 1905 a). The analytical characters of the effluent from tank No. 1 are given in Table LXIII. The free ammonia once reached 9 parts per million in the summer quarter of 1904, just after the increase in rate, but has been generally under 4 parts. The albuminoid nitrogen has been under 1 part, and the oxygen consumed under 8 parts except in one quarter. The nitrates, on the other hand, have not fallen below 20 parts, indicating a very high degree of purification, and dissolved oxygen has constantly been present. The increase in rate from 0.1 to 0.2, and again from 0.2 to 0.4, did not appreciably alter the quality of the effluent.

The surface of the filter, even at these high rates, has not required excessive care. It was scraped in August, 1903, and November, 1904, and raked once and scraped once in March, 1905. The total material removed in three scrapings during two years of operation amounted to a layer 0.48 inch thick, or 1,600 cubic inches. This is equivalent to 0.36 cubic yard per million gallons of sewage filtered.

Tanks Nos. 24 and 25 were put in operation in March, 1904, in order to compare the treatment of septic effluent with the purification of crude sewage as conducted in tank No. 1. All three were alike in construction. Tanks Nos. 24 and 25 were throughout operated at a rate of 0.4 million gallons per acre per day, taking four daily doses at six-hour intervals. Tank No. 24 received the effluent from tank No. 7, which had been septicized for twelve hours; tank No. 25 that from tank No. 9, which had been septicized for twenty-four hours. The analyses of the effluents from tanks Nos. 24 and 25 are shown in Table LXIII. In each of the three tanks studied the nitrates increased rapidly during the first months of operation (nine months in the case of tank No. 25, six months in the other two cases) and then fell to a somewhat lower value.

Fig. 17 brings out more clearly the relative quality of the three effluents, showing that from tank No. 1, which took crude sewage, to be the best. In the figure the blocks for sewage constituents represent not the septic effluent applied, but the crude sewage before treatment. It will be noticed that the average sewage applied to tank No. 1 was stronger than that treated by septic tanks Nos. 7 and 9 and filters Nos. 24 and 25. Nevertheless, the free and albuminoid ammonia values are lower and the nitrates higher after sand filtration alone than after combined septic and sand treatment.

In the condition of the surface, the filters receiving septic effluent showed a slight but distinct advantage. During fifteen months of operation tank No. 25 was raked over twice, in September, 1904, and March, 1905, but not scraped. Tank No. 24 was raked on the same dates and also scraped once in March, 1905. This scraping was rendered necessary by a rather unusual phenomenon, the deposition of a thin layer of finely divided sulphide of iron formed by decomposition of sulphates in the septic tank. After one removal this layer did not again form. It is probable that experiments extending over a longer period might have shown greater advantages in the septic process in relation to the permanency of filtering surface.

TABLE LXIII.—*Quarterly averages of analyses of effluents from slow sand filters.*

TANK NO. 1, 2 FEET DEEP, TAKING CRUDE SEWAGE.

Date.	Temperature (° F.).	Analyses (parts per million).							
		Color.	Turbidity.	Nitrogen as—				Oxygen consumed.	Oxygen dissolved.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
June to August, 1903	65	0	....	0.4	4.7	0.17	5.1	3.9	....
September to November, 1903	57	0	....	.5	1.9	.67	20.9	3.9	3.5
December, 1903, to February, 1904	39	4	....	1.5	2.9	.57	41.7	4.5	....
March to May, 1904	54	15	....	.4	2.1	.35	23.5	5.5	9.6
Yearly average	56	4	....	.6	2.9	.48	19.6	4.3	5.3
June to August, 1904	67	26	....	.8	9.3	.27	26.8	8.5	6
September to November, 1904	54	47	....	.5	3.5	.27	22.3	7.4	5.4
December, 1904, to February, 1905	41	0	....	.4	3.8	.34	24.7	4.3	8.1
March to May, 1905	43	8	....	.8	5.4	.38	22	7.2	5.6
Yearly average	52	26	....	.6	5.4	.32	23.9	6.8	6.3
General average	54	19	....	.6	4.2	.39	22.3	5.6	6.1
TANK NO. 2, 1 FOOT DEEP, TAKING CRUDE SEWAGE.									
June to August, 1903	64	....	....	0.2	20	0.18	8.5	11.6	0
September to November, 1903	54	....	....	1.9	19.4	.31	3.1	25.8	0
December, 1903, to February, 1904	40	....	210	1.8	25.3	0	0	35.7	0
March to May, 1904	54	....	350	2	20.1	.01	0	17.7	.2
Yearly average	54	....	255	1.9	17.6	.20	4.6	21.2	0
June to August, 1904	67	....	110	2.5	17.6	.55	1.2	17.9	0
September to November, 1904	56	....	165	3.5	18.3	.33	4.5	25.6	3.5
December, 1904, to February, 1905	42	....	165	3.5	12.6	.23	2.9	28.3	1.9
March to May, 1905	44	....	45	2.8	16.5	.57	2.3	19	0
Yearly average	54	....	135	3.2	16.1	.36	2.9	23.7	1.8
General average	54	....	170	2.5	16.9	.28	3.5	22.4	.9
TANK NO. 24, TAKING 12-HOUR SEPTIC EFFLUENT.									
March to May, 1904	53	18	....	1.6	10.4	0.25	0.1	6.8	8.5
June to August, 1904	68	20	0	.5	2.7	.60	19.2	7.1	6.6
September to November, 1904	52	6	5	.8	4.7	.17	28.5	5.4	8.5
December, 1904, to February, 1905	42	18	0	.7	3.9	.14	17.9	6.2	8.8
March to May, 1905	45	8	0	.6	5	.29	20	7.1	4.8
Yearly average, June 1904, to June, 1905	53	15	0	.6	4	.32	21.3	6.5	7.4
General average	53	15	0	.8	5	.31	19.9	6.5	7.5
TANK NO. 25, TAKING 24-HOUR SEPTIC EFFLUENT.									
March to May, 1904	53	18	....	1.6	10.5	0.28	1.5	7.1	4.7
June to August, 1904	68	17	0	.5	4.1	.24	15.7	6.2	5
September to November, 1904	53	20	5	.9	5.6	.10	14.6	7	10.8
December, 1904, to February, 1905	42	53	0	.8	3.2	.12	26.4	4.3	9.3
March to May, 1905	45	21	0	.7	7.3	.25	18.4	8.5	3.4
Yearly average, June 1904, to June, 1905	54	44	0	.7	4.9	.18	18.8	6.4	7.5
General average	54	43	0	.9	5.6	.19	16	6.5	7.2

In general, the results obtained indicate that in reducing the depth of a sand filter it is not safe to go below 2 feet. One foot of sand is insufficient to effect purification, while a 2-foot bed may yield admirable results. With regard to the value of preliminary septic treatment of Boston sewage before sand filtration, it appears that effluents from the combined process are slightly inferior to those obtained by the sand process alone, while the care of the surface is more difficult when crude sewage is treated. These experiments, it is believed, suggest that it may be possible to treat crude sewage by sand filtration at higher rates than have heretofore been recommended. The operation of filter beds under practical conditions is of course more difficult than in small-scale experiments. In the first place the distribution on large beds is often incomplete, while it is easy in small tanks to obtain perfect distribution. Again, the effect of winter weather was minimized in these experiments. It will be noticed in the tables that the quarterly temperature averages for the sand-filter effluents did not fall below 39° F. In order to estimate the actual importance of this point in outdoor filters, the ratios which the values of free and

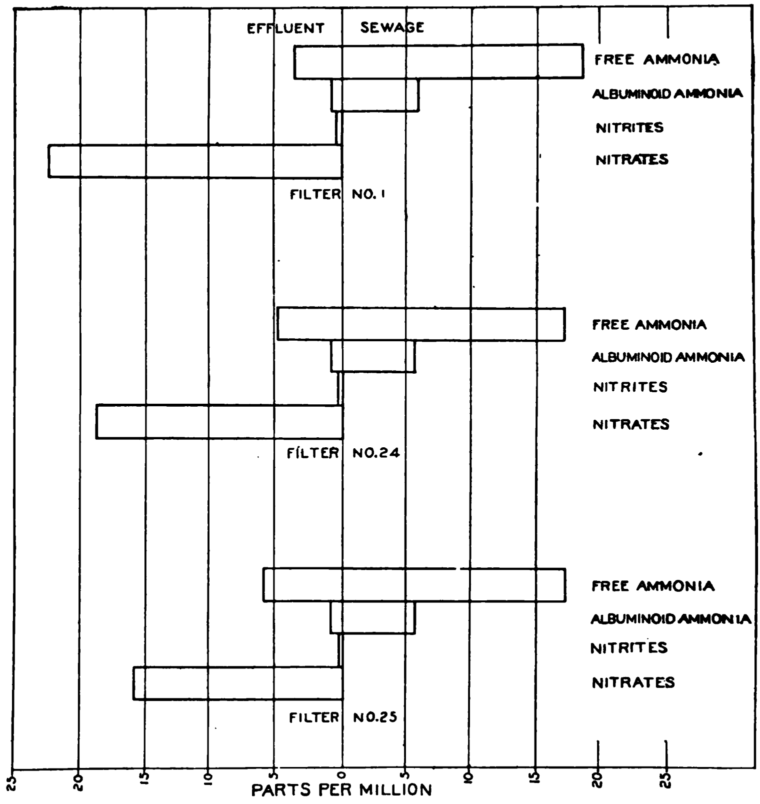

FIG. 17.—Comparison of various forms of nitrogen in crude sewage and sand-filter effluents.

albuminoid ammonia, oxygen consumed, and nitrates for each month bear to the yearly average at Lawrence and Brockton have been calculated and are given in Table LXIV.

TABLE LXIV.—*Monthly variations in sand-filter effluents at Brockton and Lawrence, Mass.*

[Yearly average—100.]

	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
FREE AMMONIA.												
Brockton	100	163	192	171	134	92	79	63	50	50	50	83
Lawrence	213	269	204	168	84	48	16	6	8	14	32	120
ALBUMINOID AMMONIA.												
Brockton	87	130	130	174	87	87	87	87	87	87	87	87
Lawrence	175	171	150	132	92	76	67	58	62	49	62	117
NITRATES.												
Brockton	85	70	67	81	90	112	118	115	133	129	110	96
Lawrence	48	38	59	100	139	140	120	116	128	125	109	75
OXYGEN CONSUMED.												
Brockton	84	132	152	178	100	84	72	68	68	84	92	108
Lawrence	170	167	149	122	84	70	69	61	62	64	61	124

The Lawrence figures are the averages of the ratios for tanks Nos. 1, 2, 3, 4, 6, and 10, from 1895 to 1900, calculated from Clark's analyses (1896–1901). For Brockton the figures used cover the period 1897 to 1904 (Brockton, 1898–1905). A regular seasonal variation is indicated, the organic constitutents reaching their maximum in February with the small Lawrence tanks and in March with the large Brockton filter. The nitrates show a reciprocal curve, being lowest in February. The maximum monthly deviation amounts to about 100 per cent, the worst monthly averages being twice as high as the average in organic matter. This probably furnishes a fair measure of the amount of damage to effluents by winter weather.

The interference with the surface of the beds by winter weather is much more serious, and the treatment of crude sewage by intermittent sand filtration at a rate of 0.4 million gallons per acre per day can not be recommended. It is believed, however, that experiments out of doors and on a larger scale are well worth making in order to see if the common rates of 0.06 to 0.1 can not be somewhat increased. No doubt beds operated at higher rates will require more attention paid to their surfaces, but it is a question if the raking and scraping incident to the filtration of a given volume of sewage will be increased by filtering it through a smaller area. It seems probable that the stable material deposited on the surface of a sand filter bears a fixed ratio to the amount of sewage filtered; the same thing is very likely true of the fatty material which, as Clark has pointed out, penetrates below the surface and gradually decreases the efficiency of an old sand bed. These inevitable deposits will not be increased by higher rates, but will be simply concentrated on a smaller area, while the oxidizable organic material can apparently be nitrified under proper conditions at considerably higher rates than 0.1. The difficulty of scraping during severe winter weather will probably furnish the most serious obstacle to increased rates of filtration.

As a rule, sand filters have been constructed without special care and operated at haphazard. As this process comes into competition with the more elaborate modern methods, it is evidently worth while to see what can be done by applying to it the same expert care which is understood to be required by a contact or a trickling filter. For example, the difficulty of distribution may largely be overcome on a practical scale by careful grading and the use of proper distributors, if it is clear that this is worth doing. The division of the entire daily dose into three or four portions, applied at equal intervals during the twenty-four hours, is an expedient which would certainly largely increase the capacity of any of the Massachusetts beds now operated on the principle of daily or even less frequent dosing. This could be accomplished by the use of automatic devices, as at Wauwatosa and other plants in the Middle West. It has been tacitly assumed that the good results obtained at these filtration areas were wholly due to the preliminary treatment of the sewage in the septic tank. It is possible that they may be in part the result of careful operation and the application of several doses during the twenty-four hours.

PURIFICATION IN CONTACT BEDS OF COARSE MATERIAL.

The experiments at this station on the contact bed were planned to bring out the influence on the results of the treatment of each of the following points: Size and kind of filling material; depth of material; double and single contact process; treatment of crude and septic sewage; and rate of operation. The filters themselves have already been described in full detail (pp. 103–105). For convenience of reference, however, the main facts concerning the filter and its operation will be restated in each case.

Of the seven primary contact beds all are 4 feet square in area. Tanks Nos. 11, 12, 13, 14, and 16 are each 6 feet deep, and Nos. 18 and 20 are each 4 feet deep.

In all cases the method of operation was as follows: The bed was filled during the course of an hour, allowed a two hours' contact, emptied in about half or three-quarters of an hour, and allowed to stand empty until the next filling. The filling was in all cases continuous, and after the first six months two or more fillings of the tank per day were evenly distributed over the twenty-four hours.

Tanks Nos. 11, 12, 13, and 14 were run alike throughout the experiments. During July and August, 1903, they received one filling per day. The rate was doubled August 31, 1903, increased to four fillings January 1, 1904, and reduced to three fillings June 24, 1904. During the whole period after August, 1903, tank No. 16, the counterpart of No. 13, was run at three fillings. Owing to the superior results obtained from tank No. 16 at three fillings over tank No. 13 at two the rate of the first four filters was increased to four fillings. This, after a fair trial, was found to be excessive, and the rate of three fillings per day was adopted as the most favorable.

Tank No. 11 was filled with coke about 2 inches in diameter. During the period from June, 1903, to June, 1905, it was run at an average rate of 1.8. No material was removed from the surface during the experiment and no serious clogging occurred. The effluent as a rule was turbid and putrescible and not satisfactorily purified.

Tank No. 12 was filled with crushed stone 1 inch to 1½ inches in diameter. During the two-year period it was run at an average rate of 1.4. No material was removed from the surface, although toward the end of the period a considerable deposit had accumulated, which would have required removal in a short time. The quality of the effluent improved steadily during the second year and was at its best at the conclusion of the experiment. During the spring of 1905 the effluent generally passed the incubator test. The purification effected by this filter was largely due to the straining action of the sludge layer on its surface.

Tank No. 13 was filled with crushed stone one-fourth to one-half inch in diameter. It was run throughout the two-year period at an average rate of 1.2. April 6, 1904, ten months after starting this filter, it was necessary to remove a 2-inch layer of deposit from the surface. This material was earthy in appearance and odor, and was easily removed without appreciably disturbing the stones. The clogging material extended to a depth of a few inches within the bed, but below the surface of the stones was not disturbed. The total weight of the substance removed was 26 pounds; its composition on analysis was as follows: Moisture, 41 per cent; loss on ignition, 6.9 per cent; organic nitrogen, 0.1 per cent. March 21, 1905, 2 inches of mixed deposit and filter material were removed. The material of the filter was clogged badly to a depth of 6 inches, below which the stones were clean. This material was similar to that first removed and was not analyzed, except that the stones were separated from the deposit in a sample of the mixture. The total weight removed was 141 pounds, of which 56 per cent, or 79 pounds, was deposit. The effluent from this filter has been uniformly good and those incubator tests which were made on it showed it to be always nonputrescible. Here still more than with tank No. 12 the straining effect of the surface deposit played an important part.

Filter No. 14 was filled originally with crushed stone one-half to 1 inch in diameter. During the year of its operation, from July, 1903, to June, 1904, it received sewage at an average rate of 1.4. No material was removed from its surface, although at the end of the year there was a considerable accumulation of deposit. The effluent was at all times intermediate between those of No. 12 (1½-inch stone) and No. 13 (one-half inch stone). At the end of the first year the filter was discontinued to make room for an experiment with a brick filter, No. 14A, on the plan of Dibdin's multiple-surface bed, the construction of which has already been described (p. 105). This filter was run throughout the second year at an average rate of 2. No material has accumulated on the surface, owing to the very open construction. The effluent of the filter has been uniformly turbid and putrefactive.

Filter No. 16 is exactly like No. 13, and was planned originally to run parallel with it except as to rate, in order to study the effect of two different rates under otherwise like conditions. As already stated, it was concluded from the work of this filter that three fillings per day were better than two and later that three were better than four. This point having been established the filter was used for experiments of a special character, the results of which have already been published (Phelps and Farrell, 1905). During the second year it was run like No. 13 in all respects. Tank No. 16, however, was not cleaned at the beginning of the second year, and therefore effected a somewhat higher purification from its greater straining action. Its average rate was 1.6.

Tanks Nos. 19 and 20 are each 4 feet deep and filled with crushed stone 1 inch to 1½ inches in diameter. They were run from June, 1903, to January 1, 1904, with two fillings per day. From January 1, 1904, to the conclusion of the experiments they were given three fillings per day. In all respects they were run as nearly alike as possible, No. 19 receiving septic sewage from septic tank No. 10 (thirty hours old) and No. 20 receiving crude sewage. The effluents from these filters were treated on secondary tanks Nos. 17 and 18, respectively. The purification by No. 19, which took septic sewage, has never been satisfactory, the effluent being at all times foul and dark colored and generally putrescible. The effluent of No. 20 has been much more satisfactory from the start. It is also a striking fact that the effluent from No. 20 has been fully as good as that from the fine-stone filters Nos. 13 and 16, and always superior to that from No. 12, from which it differs only in depth and in its consequent lower rate.

Capacity measurements were made on each bed once a week by discharging the effluent into a measuring tank as described above (p. 106). The average results by quarters are brought together in Table LXV. The results are all expressed in percentages of the total cubic capacity of the empty tank. The initial liquid capacity varied from 39 to 48 per cent, the highest values of course being found in the brick and coke beds. The single-contact beds taking crude sewage all decreased in capacity rather steadily, reaching a final value after two years of 26 to 33 per cent. The figures do not furnish evidence that the falling off had reached its limit, as was shown at Manchester. The Dibdin brick filter still showed 40 per cent of open space after one year of operation. The capacity of tank No. 19, which received septic effluent, was maintained at 38 per cent, and the secondary beds, Nos. 17 and 18, retained a capacity of over 35 per cent. The capacity of tank No. 20, which had fallen from 41 to 26 per cent in two years, was measured in August, 1905, after three months of rest, and had risen to 32 per cent.

TABLE LXV.—*Capacity of contact filter, by quarters.*

[Percentage of cubic capacity of empty tank.]

No. of filter.	Initial.	1903-4.				1904-5.			
11	46	......	44	41	39	38	38	35	32
12	40	37	......	35	33	33	32	31	30
13	44	37	......	36	36	35	34	......	33
14A	48	......	......	......	......	48	47	47	40
16	42	34	......	30	......	......	......	31	30
17	39	36	......	34	37	37	37	......	35
18	42	......	37	36	38	38	37	......	37
19	41	40	......	......	39	39	38	......	......
20	41	39	37	......	33	32	31	......	26

It is necessary to distinguish clearly between the surface clogging, due to the accumulation of material on the surface of the bed, and the true loss of capacity which affects the lower part of the filter. Since in these capacity measurements the tank was always filled just to the original surface of the stones, the former phenomenon in no way affects the results. The surface clogging depends directly on the size of material used, being greatest with the fine beds. In the present experiments it was necessary to clean the one-half-inch stone beds once a year, while the 1½-inch beds were just clogging so seriously as to render cleaning necessary at the end of the second year. The surface layer does not extend more than a few inches into the bed, and its removal is a simple matter which could be managed as easily as the scraping of a sand filter. It must, however, be reckoned with in the cost of operation.

The true loss of capacity, on the other hand, affected tanks Nos. 11, 12, 13, and 16 about equally, amounting in each case to a reduction of about one-fourth of the original open space. The ratio of the final to the initial capacity was 70 per cent for No. 11, 75 per cent for No. 12, 75 per cent for No. 13, and 71 per cent for No. 16. Tank No. 20 showed a greater reduction, to 63 per cent of its original capacity, probably because the material carried into the interstices is proportionately greater with a shallow bed. On the other hand, the secondary beds lost only about one-tenth of their open space, the ratio of final to initial capacity being 90 per cent for No. 17 and 88 per cent each for Nos. 18 and 19. The primary bed taking septic effluent lost only 7 per cent of its original capacity in twenty months of operation.

TABLE LXVI.—*Quarterly averages of analyses of contact-filter effluents.*

TANK NO. 11, PRIMARY-CONTACT BED OF 2-INCH COKE.

Date.	Temperature (°F.).	Turbidity.	Analyses (parts per million).								
			Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.	
			Total.	In solution.	In suspension.						
June to August, 1903	67	......	4.2	2.7	1.5	30.8	0.07	0	23.8	......	0
September to November, 1903	60	......	3.1	2.3	.8	23.6	.44	0	28.8	......	0
December, 1903, to February, 1904	45	......	4.4	3.3	1.1	30.3	.40	0	30.7	......	0
March to May, 1904	52	150	3.6	2.1	1.5	13.8	.06	0	20.5	18.2	0
Yearly average	57	150	3.7	2.5	1.2	23.1	.24	0	25.7	18.2	0
June to August, 1904	69	160	2.7	1.8	.9	19.3	.25	0	23.7	20.1	0
September to November, 1904	59	120	3.1	2.1	1	14.5	1.60	5	20.6	15.9	.4
December, 1904, to February, 1905	44	90	2.4	1.7	.7	14	.30	1.3	15.6	11.4	2
March to May, 1905	43	140	2.8	2.1	.7	13.8	.35	1.2	16.7	13.2	.5
Yearly average	57	130	2.8	1.9	.9	15.4	.61	1.9	19.1	15.2	.7
General average	57	130	3.2	2.2	1	18.9	.45	1.1	22.1	15.5	.5

TANK NO. 12, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE.

Date.	Temperature (°F.).	Turbidity.	Albuminoid ammonia, Total.	In solution.	In suspension.	Free ammonia.	Nitrites.	Nitrates.	Oxygen consumed, Total.	Soluble.	Oxygen dissolved.
June to August, 1903	67	......	4.6	2.9	1.7	20.4	0.01	0	30.9	......	0
September to November, 1903	60	......	3.3	2.4	.9	25.5	.66	0	40.6	......	0
December, 1903, to February, 1904	46	......	3.6	2.5	1.1	24.3	1.25	0	32	......	0
March to May, 1904	52	120	3.2	1.9	1.3	9.9	.02	0	22	19.2	0
Yearly average	57	120	3.7	2.5	1.2	20.6	.41	0	32.7	19.2	0
June to August, 1904	69	210	3	1.9	1.1	20.7	.02	0	28.7	22.8	0
September to November, 1904	59	140	3.3	2.1	1.2	15.9	1.43	2.3	21.4	14.9	0
December, 1904, to February, 1905	45	110	3	2	1	15.4	.30	1.5	18.1	15.2	.7
March to May, 1905	44	80	2.1	1.6	.5	11	.68	3.7	14.4	12	1.8
Yearly average	56	130	2.8	1.9	.9	15.4	.61	1.9	20.1	15.9	.6
General average	57	130	3.2	2.1	1.1	17.6	.52	1.3	25.3	16.3	.4

TANK NO. 13, PRIMARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE

Date.	Temperature (°F.).	Turbidity.	Albuminoid ammonia, Total.	In solution.	In suspension.	Free ammonia.	Nitrites.	Nitrates.	Oxygen consumed, Total.	Soluble.	Oxygen dissolved.
June to August, 1903	68	......	4.5	2.8	1.7	19.1	1.03	0	20.7	......	0
September to November, 1903	60	......	1.8	1.3	.5	12.7	1.33	3.5	21	......	.4
December, 1903, to February, 1904	45	......	1.7	1.3	.4	16.8	.47	1.3	14	......	0
March to May, 1904	52	70	1.9	1.3	.6	7.3	.36	5	12.3	11.2	.1
Yearly average	57	70	2.5	1.7	.8	13.6	.98	2.2	18.2	11.2	.3
June to August, 1904	68	90	1.6	1.2	.4	12.9	.18	1.9	16.6	13.7	0
September to November, 1904	59	70	1.6	1.2	.4	11.2	.73	15	11.9	9.5	2.1
December, 1904, to February, 1905	44	30	1.7	1.6	.1	5.7	.51	12.3	7.4	6.4	3.5
March to May, 1905	41	40	1.2	1.1	.1	6	.48	8.1	9.4	8.7	.7
Yearly average	56	60	1.5	1.3	.2	8.9	.46	9.5	11.3	9.6	1.5
General average	56	60	2	1.5	.5	11	.69	7.2	14.3	9.8	1.4

TABLE LXVI.—*Quarterly averages of analyses of contact-filter effluents*—Continued.

TANK NO. 14, PRIMARY-CONTACT BED OF ONE-HALF TO 1 INCH STONE.

Date.	Temperature (°F.).	Analyses (parts per million).									
		Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.			
			Total.	In solution.	In suspension.				Total.	Soluble.	
June to August, 1903	67	......	4.9	3	1.9	19.9	0.03	0	32	......	......
September to November, 1903	60	......	2.9	2.2	.7	24	.89	0	31.8	......	0
December, 1903, to February, 1904	45	......	3.4	2.3	1.1	22.5	.87	0	31	......	0
March to May, 1904	51	160	3.3	2.1	1.2	11.4	.13	.8	16.3	14	2.5
Yearly average	57	160	3.6	2.4	1.2	20	.49	0	28.3	14	.4

TANK NO. 14A, PRIMARY-CONTACT BED OF BRICK.

Date.	Temperature (°F.).	Turbidity.	Albuminoid ammonia, Total.	In solution.	In suspension.	Free ammonia.	Nitrites.	Nitrates.	Oxygen consumed, Total.	Soluble.	Oxygen dissolved.
June to August, 1904	68	250	4.1	2.5	1.6	18.1	0.09	0.1	31	21.8	0.1
September to November, 1904	59	190	4.7	2.5	2.2	16.2	.27	.6	25.1	18.6	1.6
December, 1904, to February, 1905	45	170	3.3	2.5	.8	14.8	.25	.7	25.8	21	3.7
March to May, 1905	43	180	3.5	2.1	1.4	16 4	.23	.2	27.7	19.9	.2
Yearly average	57	200	3.9	2.4	1.5	16.4	.23	.4	27.5	20.4	1.4

TANK NO. 16, PRIMARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

Date.	Temperature (°F.).	Turbidity.	Albuminoid ammonia, Total.	In solution.	In suspension.	Free ammonia.	Nitrites.	Nitrates.	Oxygen consumed, Total.	Soluble.	Oxygen dissolved.
June to August, 1903	67	......	3.7	2.7	1	16.4	1.08	0	20	......	0
September to November, 1903	61	......	1.9	1.4	.5	11.8	.85	0	16.8	......	.7
December, 1903, to February, 1904	51	......	2	1.2	.8	23.5	1.50	0	15	......	0
March to May, 1904	54	70	1.8	1.2	.6	5.9	.60	1	14.3	12.2	.3
Yearly average	60	70	2.2	1.6	.6	12.4	.90	.1	16.5	12.2	.6
June to August, 1904	69	90	1.6	1.3	.3	6.6	1.34	5.2	13.4	11.3	1.2
September to November, 1904	58	90	1.6	1.3	.3	5.6	.63	27.4	11.7	10.3	1.7
December, 1904, to February, 1905	45	50	1.3	1.1	.2	3.9	.46	11.1	7.8	7	2.3
March to May, 1905	......	20	1	.9	.1	4.7	.38	8	7.5	7	0
Yearly average	57	70	1.4	1.2	.2	5.2	.78	13.1	10.4	9.1	1.6
General average	58	70	1.7	1.3	.4	8.1	.83	9.8	13.1	9.6	1.3

TANK NO. 17, SECONDARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

Date.	Temperature (°F.).	Turbidity.	Albuminoid ammonia, Total.	In solution.	In suspension.	Free ammonia.	Nitrites.	Nitrates.	Oxygen consumed, Total.	Soluble.	Oxygen dissolved.
June to August, 1903	66	......	3.1	2.1	1	20.3	1.37	0	22.3	......	0
September to November, 1903	56	......	2.5	1.9	.6	21.3	3.38	0	24.5	......	0
December, 1903, to February, 1904	49	......	2.3	1.9	.4	28.8	0	0	18.5	......	0
March to May, 1904	51	70	3.1	2.1	.9	13.6	.07	0	16.8	13.8	0
Yearly average	55	70	2.7	1.9	.8	19.7	.42	0	21.6	13.8	0
June to August, 1904	67	90	2	1.5	.5	14.3	.16	2	13.9	11.5	.3
September to November, 1904	66	50	1.3	1.1	.2	13.5	.75	8.9	11.3	10.4	.9
December, 1904, to February, 1905	43	100	2.3	1.9	.4	12.1	.28	5	14.8	12.9	1
March to May, 1905	......	90	2	1.6	.4	9.2	.02	1.6	12.8	9.5	1
Yearly average	55	80	1.9	1.5	.5	12.4	.31	6	13.3	11.2	.8
General average	55	80	2.3	1.7	.6	15.5	.35	5.2	16.9	11.7	.6

TANK NO. 18, SECONDARY-CONTACT BED OF ONE-FOURTH TO ONE-HALF INCH STONE.

Date.	Temperature (°F.).	Turbidity.	Albuminoid ammonia, Total.	In solution.	In suspension.	Free ammonia.	Nitrites.	Nitrates.	Oxygen consumed, Total.	Soluble.	Oxygen dissolved.
June to August, 1903	67	......	3.5	2.4	1.1	18.4	0.30	0	20.4	......	0
September to November, 1903	62	......	2.1	1.3	.8	15.2	.43	0	22.8	......	0
December, 1903, to February, 1904	49	......	2.6	1.8	.8	17.5	.63	0	14	......	0
March to May, 1904	58	80	2.8	1.7	1.1	12.9	.08	.4	17.2	14	.6
Yearly average	61	80	2.6	1.7	.9	15.8	.34	.1	19.8	14	.2
June to August, 1904	66	110	2.5	1.6	.9	12.9	.33	1.9	16.6	13.3	.8
September to November, 1904	57	90	1.9	1.4	.5	9	2.23	12.1	15.9	14.9	1.7
December, 1904, to February, 1905	45	70	1.2	1.1	.1	4.6	.13	15.9	10.6	10.1	2.3
March to May, 1905	......	60	1.3	.9	.4	6.5	1.26	10	10	9.3	2.4
Yearly average	54	80	1.7	1.3	.4	8.1	.89	12.1	13.4	10.7	1.7
General average	57	80	2.1	1.5	.6	11.5	.67	8.6	16.1	12.4	1.3

TABLE LXVI.—*Quarterly averages of analyses of contact-filter effluents*—Continued.

TANK NO. 19, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE TAKING SEPTIC EFFLUENT.

Date.	Temperature (° F.).	Analyses (parts per million).									
		Turbidity.	Nitrogen as—						Oxygen consumed.		Oxygen dissolved.
			Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.	
			Total.	In solution.	In suspension.						
June to August, 1903	65	......	3.5	2.6	0.9	20.8	0.08	0	32	......	0
September to November, 1903	57	......	3.1	2.4	.7	24.6	.38	0	31	......	0
December, 1903, to February, 1904	47	......	3.3	1.6	1.7	42.5	0	0	36.5	......	0
March to May, 1904	52	130	2.9	2.1	.8	11.2	0	0	25.8	20.2	0
Yearly average	56	130	3.2	2.3	.9	22	.21	0	30.4	20.2	0
June to August, 1904	67	140	3.1	1.8	1.3	25.5	.17	.8	29.1	21.6	0
September to November, 1904	57	170	3.4	1.7	1.7	17.5	.62	2.3	23.6	16.3	0
December, 1904, to February, 1905	43	150	3.8	2.5	1.3	16.9	.09	1.4	23.4	18.5	1.3
March to May, 1905	......	190	3.5	2.8	.7	19.8	0	0	30	17.4	0
Yearly average	56	160	3.5	2.2	1.3	20.1	.22	1.2	26.3	18.7	.6
General average	56	160	3.3	2.3	1	20.9	.21	.9	28	19	.4

TANK NO. 20, PRIMARY-CONTACT BED OF 1 TO 1½ INCH STONE.

Date.	Temperature (° F.).	Turbidity.	Albuminoid ammonia, Total.	In solution.	In suspension.	Free ammonia.	Nitrites.	Nitrates.	Oxygen consumed, Total.	Soluble.	Oxygen dissolved.
June to August, 1903	67	......	5.7	4.4	1.3	20.4	0.12	0	29.7	......	0
September to November, 1903	60	......	3.9	2.7	1.2	17	.40	0	25.2	......	0
December, 1903, to February, 1904	51	......	4.7	3.1	1.6	23	.05	0	32	......	0
March to May, 1904	56	130	3.7	2	1.7	16.9	.08	0	24	17.6	.6
Yearly average	59	130	4.3	3	1.3	18.4	.23	0	26.7	17.6	.1
June to August, 1904	68	150	3.8	2.3	1.5	16.9	.07	.7	23.4	17.1	.2
September to November, 1904	57	140	3.5	2.3	1.2	16.1	2.05	7.6	20.3	16.4	.8
December, 1904, to February, 1905	46	100	2.4	1.8	.6	7.5	.33	9.3	15.3	13.5	2.2
March to May, 1905	......	110	2.7	2	.7	12.6	.30	2.3	15.8	12.8	2.9
Yearly average	55	120	3	2.1	.9	12.7	.74	6.1	18.6	15	1.3
General average	57	120	3.6	2.5	1.1	15.4	.50	4	22.4	15.4	.8

TABLE LXVII.—*General averages of analyses of contact-filter effluents.*

No. of tank.	Date.	Material.	Size of material (inches).	Average rate (million gallons per acre per day).	Temperature (° F.).	Analyses (parts per million).										Capacity (per cent of cubic contents).	
						Turbidity.	Nitrogen as—						Oxygen consumed		Oxygen dissolved.	Initial.	Final.
							Albuminoid ammonia.			Free ammonia.	Nitrites.	Nitrates.	Total.	Soluble.			
							Total.	In solution.	In suspension.								
11	June, 1903, to June, 1905	Coke	2	1.8	57	130	3.2	2.2	1	18.9	0.45	1.1	22.1	15.5	0.5	46	32
12	do	Stone	1 -1½	1.4	57	130	3.2	2.1	1.1	17.6	.52	1.3	25.3	16.3	.4	40	30
13	do	do	¼-½	1.2	56	60	2	1.5	.5	11	.69	7.2	14.3	9.8	1.4	44	33
14	June, 1903, to June, 1904	do	½-1	1.4	57	160	3.6	2.4	1.2	20	.49	0	28.3	14	.4	42	......
14A	June, 1904, to June, 1905	Brick	......	2	57	200	3.9	2.4	1.5	16.4	.23	.4	27.5	20.4	1.4	48	40
16	June, 1903, to June, 1905	Stone	¼-½	1.2	58	70	1.7	1.3	.4	8.1	.83	9.8	13.1	9.6	1.3	42	30
17[a]	do	do	¼-½	1.2	55	80	2.3	1.7	.6	15.5	.35	5.2	16.9	11.7	.6	39	35
18[a]	do	do	¼-½	1.1	57	80	2.1	1.5	.6	11.5	.67	8.6	16.1	12.4	1.3	42	37
19[b]	do	do	1 -1½	1.2	56	160	3.3	2.3	1	20.9	.21	.9	28	19	.4	41	38
20	do	do	1 -1½	1.1	57	120	3.6	2.5	1.1	15.4	.50	4	22.4	15.4	.8	41	26

[a] Secondary-contact bed.

[b] Septic effluent applied.

The quarterly analyses of the effluents from the several contact beds are given in Table LXVI, and the average analyses for each bed for the whole period of operation are brought together in Table LXVII. An inspection of the latter table and of figs. 18 to 22 will bring out the comparative results attained with filling of different material and different size, with different depths of beds, with different rates of operation, with single and double contact beds, and with the treatment of crude and septic sewage.

First, as to the kind of filling material, it was desired to see if the particularly favorable results reported with the use of coke at London would be obtained with Boston sewage. Tank No. 11, filled with 2-inch coke, is fairly comparable with tank No. 12, filled with 1½-inch broken stone. The initial capacity of No. 11 was considerably higher than that of No. 12 (46 per cent against 40 per cent), and it decreased much more slowly, so that the rate on No. 11 was higher than on No. 12 with the same number of fillings. As clogging occurred in tank No. 12 during the last year of operation, its effluent improved and at the end was much better than that of No. 11. A comparison of the average analyses for the whole period, however, shows that the effluent of No. 11 was slightly better than that of No. 12, in spite of the larger size of material and the higher rate. Thus it appears that coke is somewhat superior to stone.

On the more important question of the size of material, a comparison of tanks Nos. 12 (1½-inch stone), 13 (one-half-inch stone), and 14 (1-inch stone) is instructive. The average analyses given in Table LXVII are not comparable, because tank No. 14 was operated under the conditions mentioned for one year only, and during that year the applied sewage was strongest. In fig. 18, however, the quarterly values may fairly be compared.

As might be expected, both efficiency and clogging increase as the size of the material used diminishes. Tank No. 13 gave a better effluent than tank No. 14; No. 14 a better effluent than No. 12. The effluents from the 1-inch and 1½-inch stone were never of satisfactory quality, except, in the latter case, at the very end of the experiment, while that from the one-half-inch stone was almost always clear and nonputrescible. The efficiency with half-inch material was reached, however, only at the expense of a serious clogging which necessitated the removal of 4 inches of sludge from the surface during two years of operation, leaving the body of the filter for some distance below the surface still badly clogged. These results correspond with those obtained by Dunbar and other German investigators (Dunbar and Thumm, 1902). They show that with beds of fine material a good effluent may be obtained by a single contact, but at the cost of such clogging as to necessitate somewhat frequent removal of the upper ortion of the bed. Even the 1½-inch stone showed some clogging fter two years, and with such coarse filling a single contact will not, f course, produce a stable effluent.

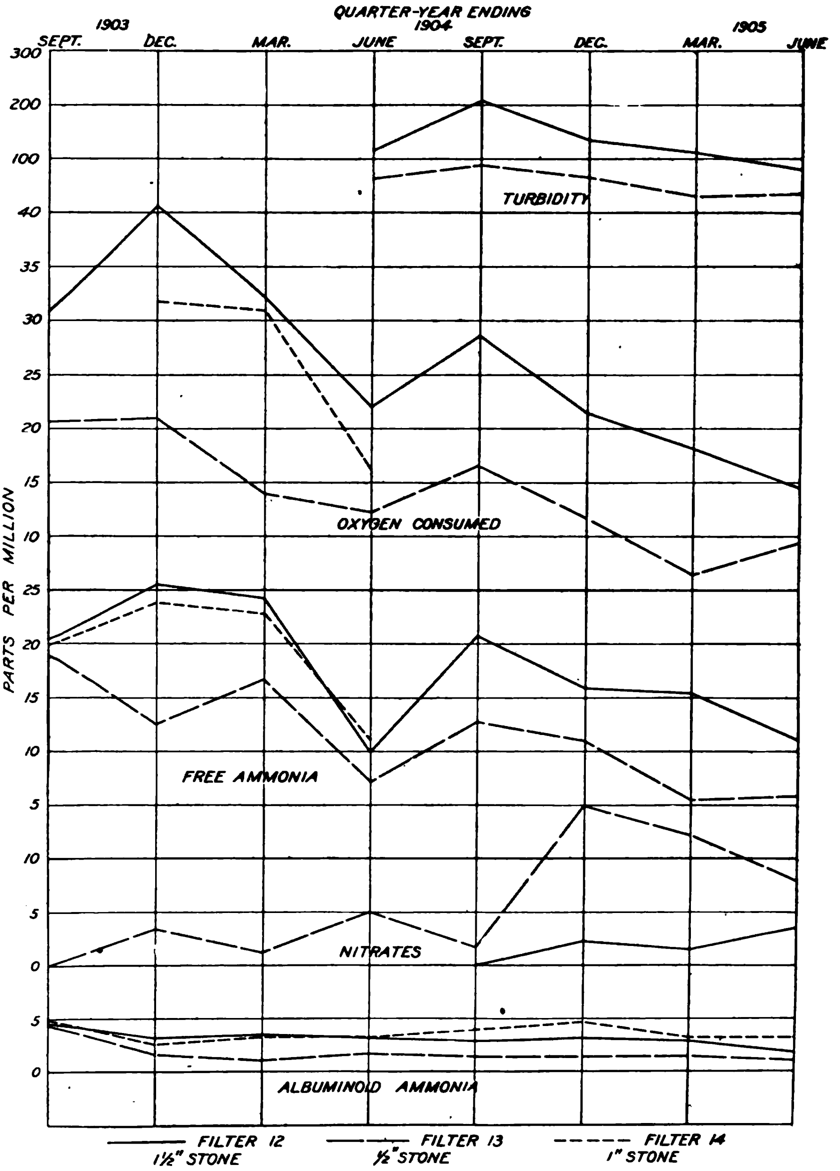

FIG 18.—Comparison of effluents from primary-contact beds of various-sized stone.

Tank No. 14A, constructed on Dibdin's plan of multiple-surface contact (Dibdin, 1904), represents a logical outcome of the desire to secure permanence by increasing the size of the material. It was filled, as described above, with bricks laid in regular tiers with the largest obtainable open space, doing away as far as possible with all straining action. Its original capacity of 48 per cent fell in a year only to 40 per cent, and with three fillings a day gave a rate of 2 to 50 per cent higher than was obtained with any other filters similarly operated with the exception of the coke bed. Its effluent compares favorably with that from tanks Nos. 11, 12, and 14, with the exception of its higher turbidity. It will be noticed that a general improvement in the character of all the effluents took place during the whole period and that it was considerably greater than can be accounted for by the weaker sewage of the second year. This improvement was manifest in all the contact beds to a greater or less degree, and is no doubt in part, but only in part, accounted for by the straining action which accompanies progressive clogging.

The percentages of albuminoid ammonia and of oxygen consumed removed by each filter during each year have been calculated, and the increase in the figures in the second year as compared with the first is shown in Table LXVIII, expressed as per cent of the first-year value. The anomalous results obtained with tanks Nos. 17 and 19 are due to the very low efficiency of No. 17 during the first year and to a deterioration of No. 19, probably due to the overseptic effluent with which it was dosed.

TABLE LXVIII.—*Improvement in percentage efficiency of contact filters in second year of operation.*

[Per cent of first-year value.]

No. of tank.	Albuminoid ammonia.	Oxygen consumed.
11	20	40
12	25	83
13	24	23
16	18	17
17	20.8	71
18	18	13
19	19	9
20	45	32

Data bearing on the effect of contact beds of different depths may be obtained by comparison of tanks Nos. 12 and 20. Both were filled with 1½-inch stone and dosed with three fillings of crude sewage per day. The depth was 6 feet for tank No. 12 and 4 feet for No. 20. The analyses of the representative effluents are shown in fig. 19. It is apparent that the results of treatment in the 4-foot bed are consistently better than in the 6-foot bed. In particular, it will be noticed in Table LXVI that the nitrification is more complete in the shallow filter, but the difference is scarcely great enough to compensate for the diminished rate.

With regard to the rate of operation it has been found, as stated above, that three daily fillings give the most satisfactory results

Between August, 1903, and January, 1904, tanks Nos. 13 and 16, otherwise similar in all respects, were operated with two and three daily fillings, respectively. Tank No. 16, with three fillings, gave the best effluent, as indicated in fig. 20. In January, 1904, the rate on tank No. 13 was doubled to four fillings. During the next few months, while the effluent from tank No. 16 was steadily improving, that from tank No. 13 deteriorated. Apparently two fillings are insufficient to maintain the maximum efficiency of the purifying organisms in the bed, while four fillings put a somewhat undue strain on their powers. After June, 1904, both beds were operated with three fillings and gave approximately the same results. Those from

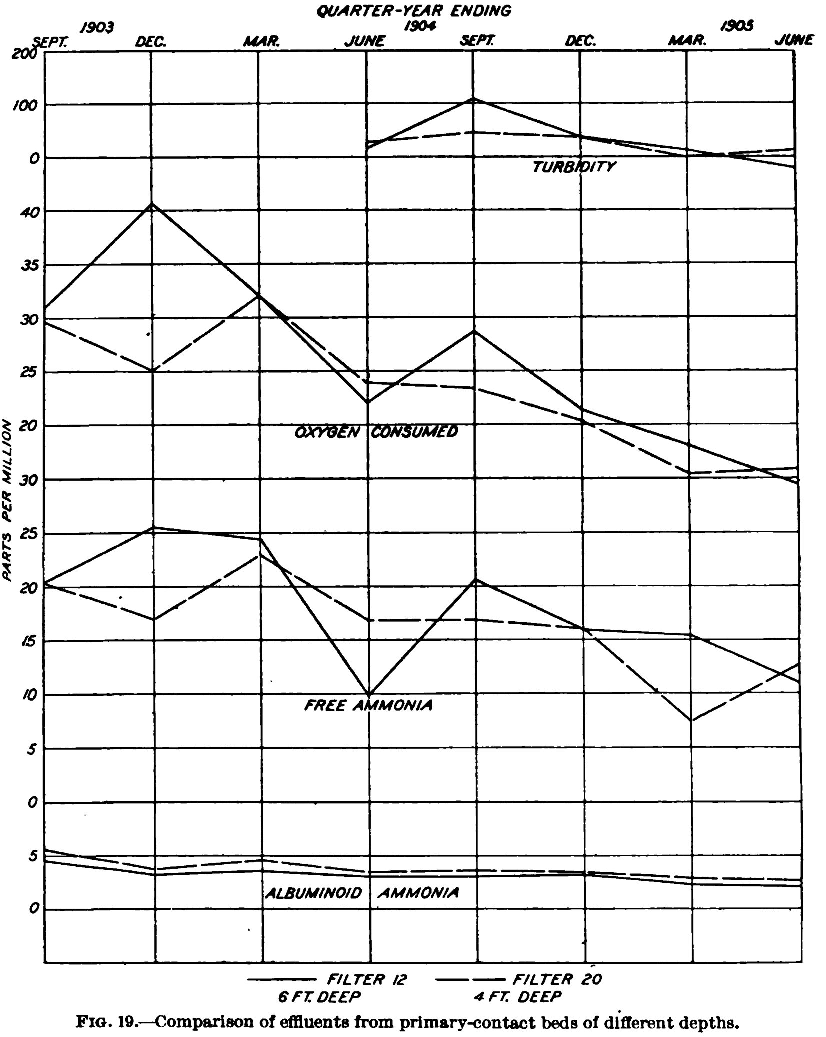

FIG. 19.—Comparison of effluents from primary-contact beds of different depths.

tank No. 16 were a little better, probably because its surface was not cleaned and a considerable straining effect was exerted.

A comparison of the operation of tanks Nos. 19 and 20 furnishes interesting results with respect to the value of preliminary septic treatment. Both were 4-foot beds of 1½-inch stone, receiving, first, two

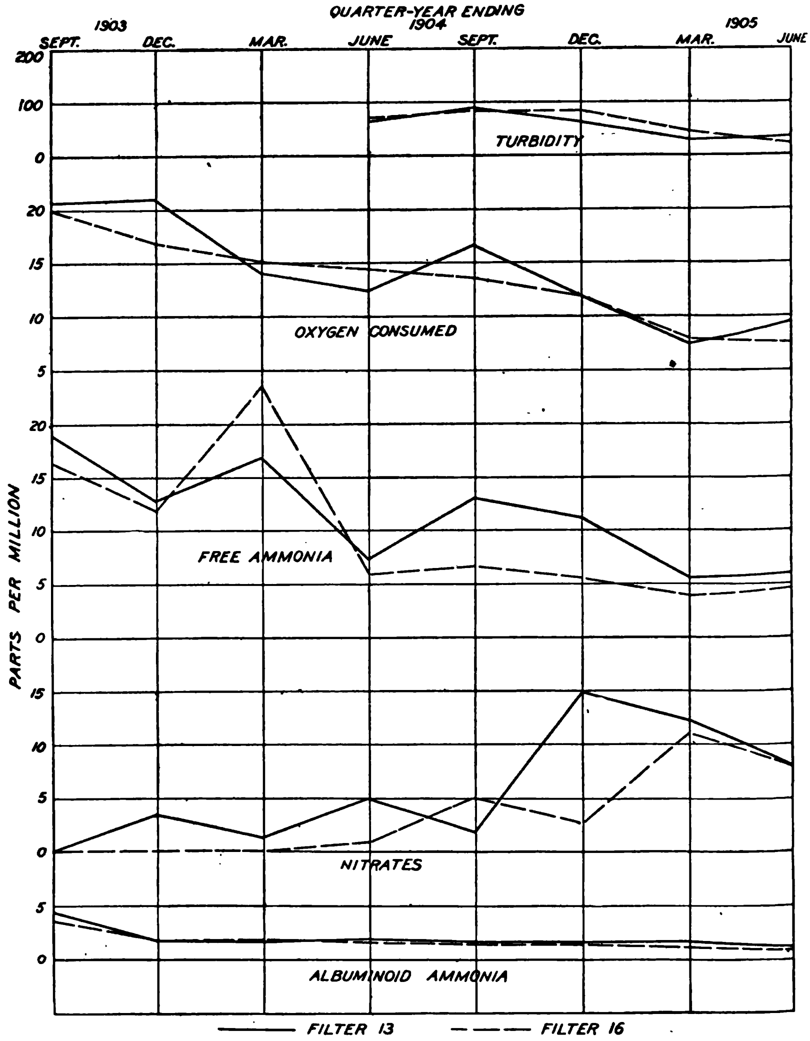

FIG. 20.—Comparison of effluents from primary-contact beds at different rates.

fillings, later, three fillings a day. Tank No. 19 received septic effluent from tank No. 10, which had been subjected to twenty-four hours of septic action and six hours' additional storage in a small dosing tank, into which the effluent from No. 10 flowed continuously. The analyses of the effluents from Nos. 19 and 20, as well as from their secondary beds, Nos. 17 and 18, are shown in fig. 21. It will be noticed that the effluent of tank No. 20 was markedly superior to that of No. 19 in every respect, except, for part of the time, in its albuminoid-ammonia content. The effluent from No. 20 was often nonputrescible, while that from No. 19 was always foul and offensive. As pointed out above, the septic treatment was efficient in preventing clogging, the final capacities of tanks Nos. 19 and 20 being 38 and 26 per cent, respectively. This advantage is, however, dearly bought, since the septic effluents from Boston sewage evidently contain substances inimical to bacterial action, which seriously interfere with subsequent purification. The possibilities of preliminary septic treatment before contact filtration can not be considered as exhausted, since only this long period (twenty-four hours' storage in the septic tank and six hours in the dosing tank) has been tried; a shorter period might remove solids without interfering so seriously with the contact bed. Furthermore, the harmful effect of the septic treatment might be largely minimized by special aeration before final treatment. All that the experiments have so far shown is that thirty hours of septic treatment yields unsatisfactory results, while crude sewage may be treated with the production of a good effluent at the risk of clogging, which would necessitate the renewal of the beds at intervals of some years. It is probable that a shorter septic period approaching more nearly the condition of plain sedimentation would maintain the capacity of the beds without corresponding harmful effects. The analyses of the effluents from the secondary filters, tanks Nos. 17 and 18, are also plotted in fig. 21. In nitrogenous constituents and in available oxygen the effluent of tank No. 18 was much better than that of No. 17. The former was clear and stable, the latter generally dark-colored and smelling of hydrogen sulphide and often failing to pass the incubator test.

The general results of these experiments on contact treatment, as measured by oxygen consumed, are plotted in fig. 22. Like fig. 7 (p. 68), for experiments at other places, it shows that a single contact will remove from one-third to one-half of the organic constituents of sewage, with the production of an improved but still putrescible effluent. Tanks Nos. 13 and 16, of one-half inch stone, form an exception, since their effluents were fairly stable toward the end of the experiments. This efficiency, as has been explained (pp. 133–134), was obtained at the expense of serious surface clogging. The double-contact treatment effected a removal of one-third to one-half of the remaining organic matter, producing a satisfactory effluent in the case of the treatment of crude sewage.

To summarize the conclusions arrived at in regard to the construction of contact beds, it appears that a 4-foot depth gives somewhat better results than a 6-foot depth, but with greater capacity loss and lower rates. Either coke, brick, or broken stone, or probably any other hard material, may be used for filling, with a slight advantage for coke. The size of the material is more important than the kind. Half-inch stone gives much better results than coarser material, yielding a nonputrescible effluent even with a single contact. The

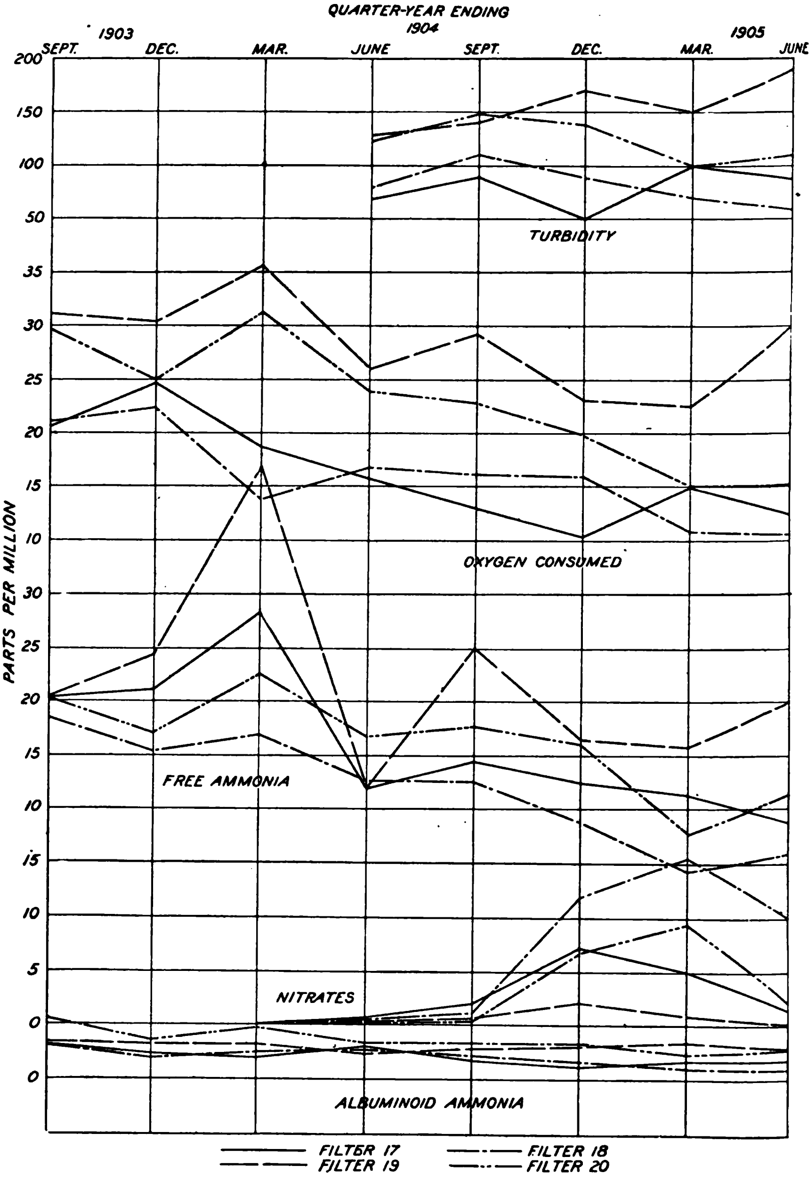

FIG. 21.—Comparison of effluents from double-contact systems taking crude and septic sewage.

urface of such beds must be cleaned once a year or oftener. With 1½-inch stone the surface deposits need not be removed so frequently, nd with still coarser material, such as 2-inch coke, the surface needs ractically no attention; but all effluents from beds of material over ne-half inch in diameter require treatment in secondary beds. In very case the beds treating crude sewage will lose capacity so rapidly s to necessitate renewal.

The contact beds have been operated most satisfactorily with three illings a day, giving a single-contact rate for 6-foot beds of 1.2 with fine-stone filling, 1.4 with coarse stone, 1.8 with 2-inch coke, and 2 with brick. The brick bed might be built, according to Dibdin's original plan (Dibdin, 1904), of slate, so as to gain a still larger capacity. With any material other than the one-half inch stone a second contact would be necessary, reducing the rate on the double system, as a whole, to between 0.6 and 1.

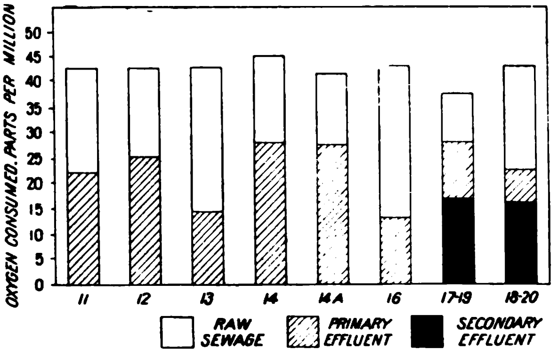

FIG. 22.—Comparison of sewages and effluents from single and double contact beds.

CONCLUSIONS BEARING ON THE TREATMENT OF BOSTON SEWAGE.

Nothing has so far been said about the process of purification by trickling over beds of coarse material. According to the results of recent English experiments this should be the most promising method of all. Three of the tanks have been operated on this principle—No. 15 for the whole two years and Nos. 22 and 23 during 1904–5. They were operated at high rates—from 1.5 to 2.5 million gallons per acre per day—and produced somewhat turbid effluents which after sedimentation were nonputrefactive. They were entirely free from surface clogging. It does not seem justifiable however to lay stress on the results obtained. The two most important points in the operation of the trickling filter are the distribution system and the effect of weather conditions. While sand filters and contact beds may fairly be tested in experiments like those recorded in this paper, it is apparent that trickling filters of only 16 square feet area, dosed with tipping buckets and operated under cover, do not furnish a criterion of actual conditions. It has therefore been decided to conduct during 1906 a series of experiments on a larger scale, out of doors, and to postpone any discussion of trickling-filter results until those experiments are completed. The conclusions in this paper will, therefore, be limited to the discussion of the septic, sand, and contact processes.

It will be necessary in any treatment to screen out large floating bodies and to settle out mineral detritus. This process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to about 1,600 pounds per million gallons of sewage and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected if desired by treatment in the septic tank. An open tank operates as well as a closed tank, and there is no marked advantage in filling the tank with stone. Varying the storage period from twelve to forty-eight hours produces no difference in the effluents which is measurable by analytical results. All the tanks removed nearly two-thirds of the suspended matter and yielded an effluent which was clear but much darkened by hydrogen sulphide. The tanks on an average received 50 pounds of nitrogen as albuminoid ammonia (dissolved and suspended), of which 30 pounds were discharged in the effluent, 15 to 17 pounds decomposed and 3 to 5 pounds stored as sludge. In the decomposition of sludge the length of the septic period is of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed, is twice as great with a forty-eight-hour period as with a twenty-four-hour period and four times as great as with a twelve-hour period.

Under the conditions of these experiments crude Boston sewage has been successfully filtered through a 2-foot bed of sand with an effective size of 0.14 millimeter, at a rate of 0.4 million gallons per acre per day, divided into four doses in the 24 hours. Such high rates should not be expected in actual practice, but it is believed that with care in construction and operation the sand filter may be efficient at higher rates than have been generally advocated. The effluents obtained from the sand beds were clear, bright, and well purified. The depth of the beds can not safely be reduced below 2 feet. Preliminary septic treatment for twelve or twenty-four hours does not improve the effluents obtained with sand filtration, although it makes the care of the surface of the beds somewhat easier.

Crude Boston sewage may be treated in single-contact beds of fine stone (one-half inch in diameter) at a rate of about 1.2 million gallons per acre per day. The effluent is only partially purified, but is generally so stable as to be discharged into a considerable volume of water without any tendency to create a nuisance. The beds clog rapidly and the surface needs much attention. The double-contact system of treatment, in primary beds of 2-inch material and secondary beds of one-half-inch material, yields a fairly well purified and stable effluent at a rate on the combined double system of about 0.7 million gallons per acre per day with beds 6 feet deep. Such a system clogs much less seriously, but nevertheless loses sufficient capacity to require renewal every few years. Preliminary septic treatment obviates this capacity loss to a considerable extent. In these experiments a thirty-hour septic period produced an effluent which without aeration was so difficult to purify as to interfere seriously with the efficiency of the contact beds. There is little doubt that this difficulty could be overcome by aeration or by shortening the septic period. The most practical of the methods which have been studied would appear to be the treatment of sewage, either sedimented or subjected to a very short period of septic action, in double-contact beds. The process of trickling filtration remains to be considered in a further report, but incomplete results obtained at the present time indicate that this method will probably prove superior to any so far tested.

ACKNOWLEDGMENTS.

The writers desire to express their acknowledgments to Mr. E. S. Dorr, of the Boston sewer department, for many courtesies; to Messrs. W. S. Johnson and Leonard Metcalf for advice in regard to certain points in the conduct of the experiments; to Prof. L. P. Kinnicutt and Mr. G. W. Fuller for suggestions concerning the presentation of results; and to Messrs. G. R. Spalding, W. H. Beers, and W. T. Carpenter for assistance in analytical work and in the preparation of tables and diagrams.

BIBLIOGRAPHY.

Alvord, J. W., 1902. Sewage-purification plants: Journal of the Western Society of Engineers, vol. 7, p. 113.

American Public Health Association, 1905. Report of committee on standard methods of water analysis: Journal of Infectious Diseases, Supplement, No. 1, p. 1.

Bailey-Denton, J., 1882. Sewage disposal, ten years' experience, with notes on sewage farming. London.

Baker, M. N., 1904. British sewage works. New York.

Barbour, F. A., 1904. The use of the septic tank in connection with sewage-disposal works: Journal of the Association of Engineering Societies, vol. 32, p. 251.

Barbour, F. A., 1905. The sewage-disposal works at Saratoga, N. Y.: Journal of the Association of Engineering Societies, vol. 34, p. 33.

Barwise, S., 1904. The purification of sewage. London.

Bokorny, 1897. Ueber die organische Ernährung grüner Pflanzen und ihre Bedeutung in der Natur: Biologisches Centralblatt, vol. 17, p. 1.

Boston, 1898. Annual report of the Street Department for the year 1897.

Boston, 1904. Annual report of the Street Department for the year 1903.

Boullanger, E., and Massol, L., 1903. Études sur les microbes nitrificateurs: Annales de l'Institut Pasteur, vol. 17, p. 492.

Bredtschneider, A., 1905. Die Reinigung des städtischen Abwassers im Brockenkörper ist rein mechanische: Gesundheits-Ingenieur, vol. 28, p. 254.

Bredtschneider, A., and Thumm, K., 1904. Die Abwasserreinigung in England: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 3, p. 1.

Brockton, 1898–1905. Annual reports of the city engineers and the sewage commissioners of the city of Brockton for the years 1897 to 1904.

Bruch, W., 1899. Das biologische Verfahren zur Reinigung von Abwässern. Berlin.

Calmette, A., 1901. Les procédés biologiques d'épuration des eaux résiduaires: Revue d'Hygiène, vol. 23, p. 2.

Clark, H. W., 1896–1905. Experiments upon the purification of sewage and water at the Lawrence experiment station: Annual reports of the Massachusetts State board of health for the years 1895 to 1904. Boston.

Clark, H. W., 1902. A study of the stability of the effluents of sewage filters of coarse materials, including investigations upon putrefaction and secondary decomposition: Annual report of the Massachusetts State Board of Health for the year 1901. Boston.

Clark, H. W., and Gage, S. D., 1905. The functions of various types of bacteria in the purification of sewage, with some methods for their quantitative determination: Engineering News, vol. 53, p. 27.

Clowes, F., and Houston, A. C., 1904. The experimental bacterial treatment of London sewage. London.

Connecticut, 1899. Report of the Sewage Commission to the General Assembly of the State of Connecticut, January session of 1899. Hartford.

Connecticut, 1903. Fourth Annual Report of the Sewage Commission to the Governor for the year 1902. New Haven.

Dibdin, W. J., 1903. The purification of sewage and water. 3d ed. London and New York.

Dibdin, W. J., 1904. Recent improvements in methods for the bacterial treatment of sewage. London.

Du Marès, J. B., 1883. Le sewage; son utilisation et son épuration. Bruxelles et Paris.

Dunbar, Dr., 1905. Ist die Wirkung der Oxydationskörper eine rein mechanische? Gesundheits-Ingenieur, vol. 28, p. 249.

Dunbar, Prof., and Thumm, K., 1902. Beitrag zum derzeitigen Stande der Abwässerreinigungsfrage, mit besonderer Berucksichtigung der biologischen Reinigungsverfahren. Berlin.

Farnsteiner, K., 1902. Leitfaden für die chemische Untersuchung von Abwässer. Berlin.

Frost, W. D., 1904. The antagonism exhibited by certain saprophytic bacteria against the *Bacillus typhosus* Gaffky: Journal of Infectious Diseases, vol. 1, p. 599.

Fuller, G. W., 1903. The composition of sewage in relation to problems of disposal: Technology Quarterly, vol. 16, p. 132.

Fuller, G. W., 1905 a. Sewage disposal in America: Transactions American Society of Civil Engineers, vol. 54, p. 147.

Fuller, G. W., 1905 b. Concerning sewage disposal from the standpoint of pollution of oysters and other shellfish, and especially with reference to their transmission of typhoid fever: Journal of Franklin Institute, vol. 160, p. 81.

Goodnough, X. H., 1903. Report of the committee on Charles River dam, p. 293. Boston.

Griggs, J., 1905. Paper read before Central States Waterworks Association at Columbus, Ohio, September 12. Abstract in Engineering News, vol. 54, p. 313.

Grünbaum, A. S., 1902. Notes on experiments on sewage disposal in Germany. Thompson Yates Laboratories Report, vol. 3, pt. 1, p. 109. London, New York, and Bombay.

HANLEY, 1904. Report of Dr. George Reid, county medical officer for Staffordshire, presented to the sanitary committee July 2.

HARRISON, W. H., 1900. The bacteriological treatment of sewage: Journal of the Society of Chemical Industry, vol. 19, p. 511.

HAZEN, A., 1890. Report of experiments upon the chemical precipitation of sewage at the Lawrence experiment station in 1889. Special Report of the Massachusetts State Board of Health on Water Supply and Sewerage, pt. 2, p. 737.

HAZEN, A., 1894. Chemical precipitation of sewage at the World's Columbian Exposition, Chicago, 1893: Annual report of the Massachusetts State Board of Health for the year 1893. Boston.

HAZEN, A., 1904. On sedimentation: Transactions American Society of Civil Engineers, vol. 53, p. 45.

HERING, R., 1888. Notes on the pollution of streams: American Public Health Association, vol. 13, p. 272.

HILL, A. B., 1897. Filtration of sewage through coal: Journal of the Sanitary Institute, vol. 18, p. 554.

HOPPE-SEYLER, 1886. Ueber die Gärung der Cellulose unter Bildung von Kohlensäure und Methan: Zeitschrift für physiologische Chemie, vol. 10, p. 201.

JACKSON, D. D., 1900. Permanent standards for use in the analysis of water: Technology Quarterly, vol. 13, p. 314.

JACKSON, D. D., and WHIPPLE, G. C., 1901. Method of calibrating turbidimeters: Technology Quarterly, vol. 14, p. 285.

JOHNSON, G. A., 1905. Sewage disposal: Ohio Sanitary Bulletin, January-March.

JORDAN, E. O., RUSSELL, H. L., and ZEIT, F. R., 1904. The longevity of the typhoid bacillus in water: Journal of Infectious Diseases, vol. 1, p. 641.

KINNICUTT, L. P., 1898. Recent work in England on the purification of sewage: Journal of the American Chemical Society, vol. 20, p. 185.

KINNICUTT, L. P., 1902. The present status of the sewage problem in England: Journal of the Association of Engineering Societies, vol. 28, p. 323.

KINNICUTT, L. P., 1905. The intermittent filtration of sewage as practiced in America: Journal of Preventive Medicine, vol. 13, p. 633.

KINNICUTT, L. P., and EDDY, H. P., 1902. The action of the septic tank on acid iron sewage: Third Annual Report Connecticut Sewerage Commission. Hartford.

LEEDS, 1900. Report on sewage disposal.

LEEDS, 1905. Report on the experiments in sewage disposal carried out at the Knostrop sewage works, Leeds, from 1898 to 1905. By Col. T. W. Harding and W. H. Harrison.

LEICESTER, 1900. Report to the highway and sewage works and farms committees, by E. G. Hawley.

LOWCOCK, S. R., 1893. Experiments on the filtration of sewage: Proceedings of the Institute of Civil Engineers, vol. 115, p. 297.

MANCHESTER, 1900 a. Expert report on treatment of Manchester sewage. Dated October 30, 1899.

MANCHESTER, 1900 b. Annual Report of the Rivers Department for the year ending March 28, 1900.

MANCHESTER, 1901. Annual Report of the Rivers Department for the year ending March 27, 1901.

MANCHESTER, 1902. Annual Report of the Rivers Department for the year ending March 26, 1902.

MANCHESTER, 1903. Annual Report of the Rivers Department for the year ending March 25, 1903.

MANCHESTER, 1904. Annual Report of the Rivers Department for the year ending March 30, 1904.

MARTIN, A. J., 1905. The sewage problem. London and New York.

MASSACHUSETTS, 1896–1905. Annual reports of the State Board of Health for 1895 to 1904.

METCALF, L., 1901. The antecedents of the septic tank: Transactions American Society of Civil Engineers, vol. 46, p. 456.

MILLS, H. F., 1890. Filtration of sewage and of water: Special Report of the Massachusetts State Board of Health on Water Supply and Sewerage, pt. 2, p. 1.

NOLL, H., 1901. Bestimmung der Saltpetersäure aus colorimetrischem Wege: Zeitschrift für angewandte Chemie, vol. 14, p. 1317.

OLDHAM, 1901. The treatment of sewage. 1900.

PAWTUCKET, 1901. Annual Report of the Board of Public Works, year ending September 30, 1901.

PAWTUCKET, 1904. Annual Report of the Board of Public Works, year ending September 30, 1904.

PHELPS, E. B., 1904. A critical study of the methods in current use for the determination of free and albuminoid ammonia in sewage: Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 87.

PHELPS, E. B., 1905 a. The interpretation of a sewage analysis: Technology Quarterly, vol. 18, p. 40.

PHELPS, E. B., 1905 b. The determination of the organic nitrogen in sewage by the Kjeldahl process: Journal of Infectious Diseases, Supplement No. 1, p. 255; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 101.

PHELPS, E. B., and FARRELL, F. W., 1905. Mode of action of the contact filter in sewage purification: Journal of Infectious Diseases, Supplement No. 1, p. 229; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 61.

PRATT, R. W., jr., 1904. Report of an examination of sewage-purification plants in Ohio: Eighteenth Annual Report Ohio State Board of Health. Springfield, Ohio.

PRATT, R. W., jr., 1905. Sewage purification, with special reference to the problem in Ohio: Journal of the Association of Engineering Societies, vol. 34, p. 310.

RAFTER, G. W., 1897. Sewage irrigation: Water-Supply and Irrigation Paper No. 3, United States Geological Survey. Washington.

RAFTER, G. W., and BAKER, M. N., 1894. Sewage disposal in the United States. New York and London.

RICHARDS, E. H., and JORDAN, E. O., 1890. Investigations upon nitrification and the nitrifying organisms: Special Report of the State Board of Health of Massachusetts on Water Supply and Sewerage, pt. 2, p. 865.

RICHARDS, E. H., and WOODMAN, A. G., 1904. Air, water, and food. 2d ed. New York.

RIDEAL, S., 1901. Sewage and the bacterial purification of sewage. London and New York.

RIVERS POLLUTION COMMISSION, 1870. First report of the commission appointed in 1868 to inquire into the best means of preventing the pollution of rivers. London.

ROBINSON, H., 1896. Sewerage and sewage disposal. London and New York.

ROECHLING, H. A., 1892. Sewage farms at Berlin: Minutes of Proceedings of the Institution of Civil Engineers, vol. 109, p. 179.

ROYAL SEWAGE COMMISSION, 1901. Interim Report of the Royal Commission on Sewage Disposal. London.

ROYAL SEWAGE COMMISSION, 1902 a. Second Interim Report of the Royal Commission on Sewage Disposal.

ROYAL SEWAGE COMMISSION, 1903. Third Interim Report of the Royal Commission on Sewage Disposal.

ROYAL SEWAGE COMMISSION, 1904 a. Pollution of tidal waters, with special reference to the contamination of shellfish: Fourth Interim Report of the Royal Commission on Sewage Disposal, vol. 2.

Royal Sewage Commission, 1904 b. Chemical report by Dr. G. McGowan: Fourth Interim Report of the Royal Commission on Sewage Disposal, vol. 4, pt. 2.

Royal Sewage Commission, 1904 c. General report: Fourth Interim Report of the Royal Commission on Sewage Disposal, vol. 4, pt. 1.

Schloesing, T., and Muntz, A., 1877. Sur la nitrification par les ferments organisés: Comptes Rendus, vol. 84, p. 301.

Schultz-Schultzenstein, 1903. Ueber die nitrificierenden Mikro-organismen der Filterkörper biologischer Abwässer-Reinigungsanlagen: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 2, p. 1: translated by A. E. Kimberly, Technology Quarterly, vol. 17, 1904, p. 186.

Schury, 1905. Die biologische Versuchskläranlage der Stadt Stuttgart auf der Prag: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 5, p. 1. Berlin.

Scott-Moncrieff, W. D., 1899. High nitrification in sewage treatment. Journal of the Sanitary Institute, vol. 20, p. 653.

Smith, J., 1901. The sewerage and sewage disposal of Burton-upon-Trent. Proceedings of the Institution of Civil Engineers, vol. 146, p. 262. London.

Stearns, F. P., 1890. The pollution and self-purification of streams: Special Report of the Massachusetts State Board of Health on Water Supply and Sewerage, pt. 1, p. 785.

Steurnagel, 1904. Die Probekläranlage zu Cöln-Niehl und die daselbst angestellten Untersuchungen und erzielten Ergebnisse: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 4, p. 1. Berlin.

Stoddart, F. W., 1893. Water analysis—the interpretation of results: The Practitioner, vol. 51, p. 378.

Stoddart, F. W., 1905. The tanking of sewage: Journal of Preventive Medicine, vol. 13, p. 571.

Thudichum, G., 1903. Bacterial treatment of sewage. London.

Thumm, K., 1902. Beitrag zur Kentnisse des sog. biologischen Verfahrens, insbesondere die bei der Herstellung und dem Betriebe biologischer Abwässerreinigungsanlagen zu beachtenden allgemeinen Gesichtspuncte: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung zu Berlin, vol. 1, p. 86.

Thumm, K., and Pritzkow, A., 1903. Versuche über die Reinigung der Abwässer von Tempelhof bei Berlin durch das biologische Verfahren: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 2, p. 127.

United States Geological Survey, 1900. Operations at river stations, 1899, pt. 1: Water-Supply and Irrigation Paper No. 35. Washington.

United States Geological Survey, 1901. Operations at river stations, 1900, pt. 1: Water-Supply and Irrigation Paper No. 47. Washington.

United States Department of State, 1895. Consular Reports, vol. 48, No. 173.

Waring, G. E., jr., 1895. The purification of sewage by forced aeration. Newport, R. I.

Warington, R., 1882. Some practical aspects of recent investigations in nitrification: Journal of the Society of Arts, vol. 30, p. 532.

Watson, J. D., 1903. The purification of sewage. Birmingham.

Weston, R. S., 1905. Notes on the determination of nitrogen as nitrates in waters: Journal of the American Chemical Society, vol. 27, p. 281.

Wilcox, J. E., and Reid, G., 1904. The importance of uniform distribution of sewage on filters: Journal of the Royal Sanitary Institute, vol. 25, p. 494.

Winslow, C.-E. A., 1905 a. The number of bacteria in sewage and sewage effluents determined by plating upon different media and by a new method of microscopical enumeration: Journal of Infectious Diseases, Supplement No. 1, p. 209; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 41.

Winslow, C.-E. A., 1905 b. A winter visit to some sewage-disposal plants in Ohio, Wi consin, and Illinois: Journal of the Association of Engineering Societies, vol. 34, p. 335.

Winslow, C.-E. A., and **Phelps**, E. B., 1905. The chemical and bacterial composition o the sewage discharged into Boston Harbor from the south metropolitan district: Jou nal of Infectious Diseases, Supplement No. 1, p. 175; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 7.

Winslow, C.-E. A., and **Willcomb**, G. C., 1905. Tests of a method for the direct microscopic enumeration of bacteria: Journal of Infectious Diseases, Supplement No. 1, p. 273; Contributions from the Sanitary Research Laboratory and Sewage Experiment Station, vol. 1, p. 119.

Woodman, A. G., **Winslow**, C.-E. A., and **Hansen**, P., 1902. A study of self-purification in the Sudbury River: Technology Quarterly, vol. 15, p. 105.

Worcester, 1905. Annual Report of the Superintendent of Sewers of the city of Worcester for the year ending November 30, 1904.

York, 1901. Report of the city surveyor on sewage-purification experiments.

Zahn, C., 1903. Weitere versuche über die Reinigung des Charlottenburger Abwässers auf Pumpstation Westend durch das biologische Verfahren: Mitteilungen aus der Königlichen Prüfungsanstalt für Wasserversorgung und Abwässerbeseitigung zu Berlin, vol. 2, p. 164.

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NOVEMBER, 1906.

N. J. Fetter

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
BOSTON

CONTRIBUTIONS

FROM THE

SANITARY RESEARCH LABORATORY

AND

SEWAGE EXPERIMENT STATION

VOL. III

REPRINTED PAPERS

BOSTON
1906

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I. The Readjustment of Education and Research in Hygiene and Sanitation. W. T. SEDGWICK. [*Proceedings of the American Public Health Association*, Volume XXXI. (1905 meeting), page 115.]

II. The Scientific Disposal of City Sewage: Historical Development and Present Status of the Problem. C.-E. A. WINSLOW. [*Technology Quarterly*, Volume XVIII. (1905), page 317.]

III. Experiments on the Purification of Boston Sewage, 1903–1905. C.-E. A. WINSLOW and EARLE B. PHELPS. [*Proceedings of the American Public Health Association*, Volume XXXI. (1905 meeting), page 16.]

IV. The Interpretation of a Sewage Analysis. EARLE B. PHELPS. [*Technology Quarterly*, Volume XVIII. (1905), page 40.]

V. The Interpretation of an Analysis of the Effluent from a Sewage Filter. EARLE B. PHELPS. [*Technology Quarterly*, Volume XVIII. (1905), page 123.]

VI. A Winter Visit to Some Sewage-Disposal Plants in Ohio, Wisconsin, and Illinois. C.-E. A. WINSLOW. [*Journal of the Association of Engineering Societies*, Volume XXXIV. (1905), page 335.]

VII. On the Present Relative Responsibility of Public Water Supplies and Other Factors for the Causation of Typhoid Fever. W. T. SEDGWICK and C.-E. A. WINSLOW. [*Journal of the New England Water-works Association*, Volume XX. (1906), page 51.]

VIII. The Toxic Effect of Certain Acids upon Typhoid and Colon Bacilli in Relation to the Degree of Their Dissociation. C.-E. A. WINSLOW and E. E. LOCHRIDGE. [*Biological Studies by the Pupils of William Thompson Sedgwick* (Boston, 1906), page 258.]

IX. The Determination of Small Quantities of Copper in Water. EARLE B. PHELPS. [*Journal of the American Chemical Society*, Volume XXVIII. (1906), page 368.]

X. The Inhibiting Effect of Certain Organic Substances upon the Germicidal Action of Copper Sulphate. EARLE B. PHELPS.

[*Biological Studies by the Pupils of William Thompson Sedgwick* (Boston, 1906), page 283.]

XI. Experiments on the Storage of Typhoid-Infected Water in Copper Canteens. EARLE B. PHELPS. [*Proceedings of the American Public Health Association*, Volume XXXI. (1905 meeting), page 75.]

PREFATORY NOTE.

Volume I. of "Contributions from the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology" originally appeared in Supplement No. I. (May, 1905) of the *Journal of Infectious Diseases*. A limited edition was also issued and distributed separately. This edition was quickly exhausted by an unexpectedly large demand, but copies of the original publication, the Supplement mentioned above, may at this writing still be purchased from the publisher of the *Journal of Infectious Diseases*, Chicago, Ill.

Volume II. of the "Contributions," the most important of the publications of the Laboratory and Station up to this point, is now in press and will shortly be issued in a large edition as Water Supply and Irrigation paper No. 185 by the United States Geological Survey. It will include a complete account of our experiments on the purification of sewage for the years 1903–1905, together with an historical digest of the sewage-disposal problem in Europe and America, and of the means proposed for its scientific solution.

Application for copies of Volume II. should be made to the Director of the United States Geological Survey, Washington, D. C.

The present Volume (Vol. III. of the series) is a collection of miscellaneous papers on sewage disposal and other sanitary subjects published in various technical or scientific journals by members of the staff of the Laboratory and Station in 1905 and 1906. During this time, thanks to the continued generosity of the anonymous donor, the work of investigation has been steadily continued, the principal workers having been, as before, Assistant Professor C.-E. A. Winslow, Biologist-in-Charge, and Earle B. Phelps, S.B., Research Chemist and Bacteriologist.

W. T. SEDGWICK,
Director.

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
BOSTON, August, 1906.

THE READJUSTMENT OF EDUCATION AND RESEARCH IN HYGIENE AND SANITATION.

By WILLIAM T. SEDGWICK,

PROFESSOR OF BIOLOGY AND DIRECTOR OF THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION, MASS. INSTITUTE OF TECHNOLOGY, BOSTON.

THE READJUSTMENT OF EDUCATION AND RESEARCH IN HYGIENE AND SANITATION.

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In Herbert Spencer's well known definition, continuous adjustment is seized upon as the essential characteristic of life, and in any vital enterprise such as business, government, education or research, frequent, if not continuous, adjustments and readjustments are indispensable. In the present paper I propose to inquire whether the time has not come for a readjustment of our definitions and methods of research and education in hygiene and sanitation. And if it turns out, as I think it will, that such is the case, I shall venture to indicate some of the steps required to be taken in order to bring about readjustment.

We shall gain in perspective more than we lose in time if we recall briefly how the conditions that now prevail orignated. In doing this we need not go further back than Pettenkofer, for with him, his associates and successors, scientific hygiene and sanitation as these exist to-day began. It is true that the Greeks valued the *mens sana in corpore sano* and earnestly strove to attain it. It is true that Combe and Kingsley and many other English laymen did good public service in the middle of the nineteenth century by preaching that cleanliness, public as well as private, is next to godliness. It is true that Johannes Müller and his successors laid the basis of a rational personal hygiene by working out the basis of a rational physiology. But the first to bring to bear upon hygiene in all its branches, so far as then known, the exact methods of chemistry, physics and physiology; the first to emphasize adequately the importance of good water supplies and especially of good sewerage; the first to examine scientificaly the ground, and ground air, and ground water, the porosity of the walls of houses and, in general, those environmental aspects of hygiene to which we give to-day the special name "sanitation" — was Max von Pettenkofer, Professor in the University of Munich, with his associates and successors.

In recognition of Pettenkofer's pioneer work and the importance of the science which it represents, a new institute, the Hygienic Institute, of which Pettenkofer was made the Director, was added to those already existing in the University of Munich and this building, located near the Physiological Institute and like that situated upon a street which now bears the name of Pettenkofer, should be a shrine of pilgrimage for all hygienists both as Pettenkofer's laboratory and as the first of a long series of hygienic institutes established since then all over the civilized world. Up to this time Pettenkofer had worked in the physiological institute with his friend and colleague Voit, so that the new science of Hygiene may be said to have sprung directly as a branch from Physiology, then as now, a fundamental member of the group of medical sciences. The connection of hygiene with medicine, or at least with physiology, is thus ancestral and phylogenetic. But while hygiene began, and must always begin, with physiology, it did not and cannot end there. Pettenkofer's own work even, soon led him into questions of public hygiene, involving, for example, chemistry, physics and engineering, into air analysis, soil physics and problems of water supply and sewage. And so urgent and promising were these problems of the public health that the physiological problems of individual or personal hygiene soon played but a small part in the work of the new Institute.

This tendency to depart from physiology thus early discoverable in this first hygienic institute, was a recognition — perhaps an unconscious recognition — of a fact which has since become perfectly clear, namely, that the sphere of hygiene is naturally separable into two distinct hemispheres, one dealing directly and chiefly with individuals or masses of individuals, the other directly and chiefly with their environment. And inasmuch as it is this tendency and this differentiation which have, as it were, thrown out of adjustment our earlier methods of research and education in hygiene, making necessary that readjustment which it is the purpose of this paper to propose and promote, we must before going further observe carefully how far this differentiation has proceeded already, and how far it is likely to go in the future.

If we examine any recent textbook professing to cover the whole field of hygiene we cannot fail to be struck with the variety, not to say incongruity of the topics treated. This is especially true of the German textbooks, taken as a whole, but is also characteristic of some English and American textbooks. Subjects as unlike as muscular exercise and street cleaning, or foods and railway sanitation, are grouped together, so that the reader who turns the pages cannot help wondering if hygiene is not the most comprehensive of sciences and a hygienist the broadest of men. Moreover a student of the science of health soon hears the words "sanitary" and "sanitation" as well as "hygienic" and "hygiene" and may well ask exactly what each and all mean. If he be interested in research rather than education he will meet not only with hygienic institutes, but also sewage experiment stations, food and drug laboratories, and laboratories of sanitary research; laboratories of sanitary chemistry, water analysis, food analysis, etc. These various differentiations are largely the outcome of the marvelous additions to our knowledge, and especially to our knowledge of the environment, within the last half century. Almost every discovery in science, almost every advance in engineering, has contributed some fact or condition of practical interest or importance to general hygiene. The pressure of population, the migration from country to city, labor-saving machinery, the growth of traveling, the enrichment of our dietaries, the factory system, high buildings, cold storage, and a thousand other modifications of our ways of living,—all these have opened up problems of hygiene previously either non-existent or unknown. To-day we are also beginning to appreciate the importance and power of the protoplasmic human mechanism, which has to struggle for existence and success under these various conditions, and to look to the physiologists for a more intimate knowledge of its normal operation.

Meantime, in America at least, research in hygiene is comparatively sporadic if not desultory, and educational opportunities are few and unsatisfactory. Hygiene is allowed only a modicum of time in our medical schools and little or no place in schools of engineering. And yet its importance to modern society is unquestioned. Never before has a higher value been set upon the working efficiency of the human machine. Never before have preventive medicine, hygiene or sanitation occupied so high a place in the public esteem. Why is it, then, we may well ask, that medical schools pay so little attention to a subject so important and at the same time so closely connected historically and practically with medical science? The answer to this question will, I believe, establish the truth of my thesis that readjustment is required, and will also reveal some of the steps required to bring about such readjustment.

In spite of its admitted importance, hygiene occupies only a very small place in our medical schools, partly, I believe, because *sanitation* has become so large a part of hygiene, and sanitation belongs in schools of engineering; and partly because for medical men there are, in our country, very few attractive positions in the applications of hygiene. Let us consider the first point more carefully. It is to-day absurd for the average well trained medical student to think of becoming an expert in such branches of hygiene as water supply, sewerage, heating and ventilation, street building, cleaning and watering, garbage collection and disposal, gas and other forms of light supply, ice supply, milk supply, the abatement of nuisances, etc. These belong rather to the sanitary engineer, sanitary chemist and sanitary biologist; to sanitation rather than hygiene.

Closer to the physician's own work, and yet almost a science in themselves, are the problems of personal hygiene, muscular exercise, sleep, foods and feeding, bathing, clothing, mental work, and the like. Half way between personal and public hygiene, lie such subjects as school hygiene and school sanitation, epidemiology, quarantine, the control of foods and drugs. If the modern medical student can find time for a thorough acquaintance with bacteriology and serum science he is probably doing all that we ought to expect of a well trained beginner in medicine or surgery. The difficulty here described suggests its own remedy. Why not begin in our readjustment by making a sharp distinction between the hygiene of the individual and that of the environment, keeping for the former the older, broader and historic term *hygiene,* and giving to the latter the term already almost universally applied to it (unless in Germany), namely ***sanitation.*** Next, why not frankly give up the pretense of teaching in medical schools of more than the most general and elementary principles of water supply, sewerage, heating and ventilation, street construction, street cleaning, street watering, plumbing, gas supply, ice supply, milk supply, and the purity of foods and drugs, leaving these to sanitarians — engineers, chemists, and biologists. Freed from these subjects, courses in hygiene might be given in medical schools which should be practically valuable to medical men, dealing as these should chiefly with its personal aspects, and yet involving many of the most important matters relating to the public health. Such courses would be essentially medical, or at least physiological, and are to-day greatly needed. I think I am within the truth in saying that in some engineering schools sanitation is to-day better taught than personal hygiene is in any medical school; and this surely ought not to be, and need not be, true.

As for research, it is idle to expect the ordinary medical man to be greatly interested in or to spend much time upon the detailed problems of water or sewage purification, even if he has — as he generally has not — the requisite training. We must expect this work to be done by engineers, chemists, and biologists, and not by physicians. And its teaching belongs in schools of science and engineering rather than in medical schools.

At the same time another and fundamental readjustment is sorely needed, which, if it could be effected, would do more to promote good teaching and research in hygiene and sanitation than any other one thing. This is the establishment of ***permanent, well-paid positions*** in the service of the public health. I am not sanguine that this readjustment — the most fundamental of all, and one which, if it could be made, would speedily bring about the others — is either easy or imminent, and yet I believe that we should never cease for an instant to proclaim its necessity or to work for it. Somehow or other, we must in America secure a large group of well-paid public health officers who shall have powers of more than local jurisdiction or at least more than local visitation, criticism and advice; who shall be supplied with laboratories and other means of experiment and investigation; and who shall be able and willing to call to their aid and co-operation, sanitary engineers, sanitary chemists and sanitary biologists. These public health officers will naturally be medical men, but they will not be ordinary medical men. They must be specially trained for the work; they must know more of infectious than of chronic diseases; more of medicine than of surgery; they must be thoroughly equipped in epidemiology and must have a general but sound elementary knowledge of sanitation; they should know and use statistics; and above all they should possess tact, courage and firmness. When the places for such men are provided the men will soon be found. A medical school will then gladly give courses, not only in hygiene but in public health, such as will prepare good candidates. I believe it to be our first duty to work for the establishment of such public health positions, and all that is needed to secure them is a general readiness to surrender some local pride and some local importance, for the sake of national progress, mutual benefit, and the advancement of science.

Meantime we must look to our universities and technical schools for the maintenance of the very best hygienic laboratories and sanitary experiment stations which they can afford, and to our states and cities for the best that money can buy. Even these are not enough. Brief but comprehensive courses in the theory and practice of hygiene, and especially personal hygiene, should be offered in all medical schools, and in the theory and practice, of sanitation, in our technical and scientific schools. In this way the road would be open to all — physicians, scientists and engineers — to become grounded in the general principles of hygiene, while for those whose tastes and abilities led them to go further, the research laboratories already mentioned, and the positions referred to, would offer an incentive and hold out inviting and honorable careers. It is hard to think of any consummation at present more devoutly to be wished for in the United States or more certain to redound to the promotion of the public health and the public welfare.

Politics must also be wholly eliminated from our boards of health, both state and municipal. There is no republican method of vaccination, no democratic plan of street cleaning. And places on boards of health must not be used as rewards of political activity. The time, if it ever existed, has gone by when a proper board of health can be made up of a political doctor, a political saloon-keeper and a political nobody; for no well-trained and self-respecting expert in hygiene or sanitation can or will long remain in the dubious and uncertain service of such weak, incompetent or shifty characters.

TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Vol. XVIII DECEMBER, 1905 No. 4

THE SCIENTIFIC DISPOSAL OF CITY SEWAGE: HISTORICAL DEVELOPMENT AND PRESENT STATUS OF THE PROBLEM

By C.-E. A. WINSLOW

(Read October 12, 1905)

The disposal of waste is a fundamental problem for all living organisms. As the body takes in food and builds it up into its own wonderful structure, so it must continually break down and give off waste products, which, as a rule, if they accumulate prove poisonous to the organism itself. And as this is the case with the individual, so is it still more the case when large numbers of organisms are closely congregated together in communities. Nevertheless the attempt at scientific waste disposal is a comparatively recent one. It really dates from the epoch-making report of the Health of Towns Commission of Great Britain in 1844, which revealed such astonishing conditions with regard to the decomposing organic matter, and the filth of all kinds which had accumulated in British cities, that it aroused British sanitarians to a strong movement for the amelioration of these conditions, and led to the development of the filth theory of disease — the theory that disease is bred in heaps of decomposing filth. This theory we now know to be wrong in its essential assumption that infective material is created *de novo* by decaying organic matter; yet it was right in laying emphasis on filth as a carrier of disease. The wonderful administrative work of the British sanitarians, acting on this partially erroneous theory, effected the greatest sanitary progress which has probably ever been known; so that whereas in 1815 the sewers of London were simply drains to carry off the storm water, the discharge of sewage into them being forbidden by law, in 1847, only three years after the report of the Health of Towns Commission, it was made obligatory to discharge all sewage into those drains.

The water carriage system, in which the sewage is diluted as promptly as possible with a large volume of water, was quickly introduced in England, and has since followed in other countries. Thus the problem of disposal was shifted one step away from the individual; instead of the individual having a small amount of waste to dispose of, the municipality has now a very much larger problem on its hands — the disposal of all the waste materials diluted with a great volume of water. For example, in Boston, on one side of the city, known as the South Metropolitan District, it is necessary in every year to dispose in some way of 1,600 tons of nitrogen as free ammonia alone, representing an enormous quantity of organic matter; and the problem is made so much more difficult by reason of the fact that the organic matter is diluted with thirty billion gallons of water.

In American sewages we find only one part in 1,000 of solid matter; in other words, there are 999 parts of water to be handled, or somewhat more than that, for every part of solid matter. The dangerous elements making up the single part in 1,000 with which we are particularly concerned in sewage disposal may be classed under three heads: organic matter, mineral matter, and bacteria. The mineral matter is harmful only under exceptional conditions, when large amounts of industrial wastes enter the sewers, and need not be considered tonight. The bacteria may be harmful when the sewage is so discharged as to reach some source of food or water supply. In the case of the water supply it is hardly fair to expect protection from the sewage expert. It is a very difficult matter indeed to produce a germ-free effluent by any process of sewage disposal, and we are now taking the position that no surface water should be used for drinking purposes without being filtered. So I think sewage experts have a right to feel that the responsibility r disease caused by the discharge of sewage into water rests most vily upon the water supply experts. This general proposition must modified in the special case where sewage is discharged into ponds and estuaries from which shellfish are taken. Here there can be no question of purifying the shellfish. It is necessary either to abandon the taking of shellfish from such waters or to purify the sewage in such a way as to remove the disease germs. This is a problem which may prove of increasing importance during the next few years, and which may make it necessary to produce a sterile effluent, or, at least, one free from pathogenic bacteria. As a rule, however, in questions of sewage disposal it is not the bacteria but the decomposing organic matter with which we are chiefly concerned. Such organic matter is composed of unstable molecules, imperfectly oxidized, which can be disposed of in two ways. First, it may decompose, putrefy, break down, with the production of offensive gases of decomposition, creating a nuisance, and in some cases, as in one or two heavily polluted rivers in Massachusetts, actually endangering the health of adjacent communities. Or, secondly, under the influence of oxygen it may undergo another process that we call nitrification, a slow burning or combustion which converts the organic matter into nitrates, or other mineral substances, without the production of foul odors and in a wholly satisfactory way. Organic matter must either putrefy or nitrify, and the aim of sewage treatment is to nitrify it. This is a difficult problem, because it involves the supply to that organic matter of one to three times its weight of oxygen, with the special conditions under which the oxygen and the organic matter will unite.

Disposal by Dilution.—The most obvious way to dispose of sewage is to throw it into the nearest body of water. Before true sewers existed the natural drains discharged into the nearest water course, and when they became filled with polluting matter the same plan was followed. Sometimes this works very well. If the volume of sewage discharged into a stream is sufficiently small, there may be enough oxygen to unite with the organic matter and enough organic life in the stream to effect that union. Under such condition there results a self-purification of the stream of a very satisfactory type. The problem changes, however, when the volume of sewage exceeds the maximum which may be absorbed by a given stream, which may be stated as one part of sewage to fifty parts of water. When that limit is exceeded, when the limit of available oxygen for the oxidation of organic matter is passed, then the conditions of putrefaction are set up. It is like Mr. Micawber's philosophy: "Annual income twenty pounds, annual expenditures nineteen ought and six, result happiness. Annual income twenty pounds annual expenditures twenty pounds ought and six, result misery." Up to a certain point everything goes well, but beyond that point conditions are totally changed, and instead of a self-purifying stream you find a foul septic tank such as Boston has possessed for some time in front of her most costly residential street, in the Fens basin. Dilution then — the discharge of sewage into water — is limited by the volume of sewage in relation to the body of water into which it is to discharge. On the seacoast the conditions for purification by dilution are ideal; and with large rivers like the Mississippi this method may be followed very satisfactorily. In smaller streams we get the septic tank condition of which I have spoken. In Massachusetts alone there are at least seven rivers so polluted as to become a public nuisance for a part of their course. The Neponset at Hyde Park and the Blackstone River below Worcester will occur to all as conspicuous examples.

Disposal on Land. — A second obvious method of sewage disposal is discharge on the surface of the soil; and this method has been followed from time immemorial. In the little city of Bunzlau in Prussia there was a public water supply as early as 1559, piped from a spring, and in connection with it was installed a sewerage system and a system of disposal on a sewage farm. At this time it was thought that you could not only dispose of sewage satisfactorily by discharging it on land, but that a good deal of profit would come from the fertilizing effect of the material. So the practice of sewage farming spread, and in England, just after the period of sanitary reform in the early sixties, grew up very rapidly. A number of irrigation areas successfully operated today were laid out in England at that time. The largest and most famous examples of this process are the sewage farms at Paris and Berlin. In Berlin the flow of sewage from a population of 1,750,000 is treated on 23,000 acres of land at a rate of 3,000 gallons per acre per day. Crops are cultivated and the farm is operated with fair success, the operation being carried out by convicts under military discipline. The process of irrigation, or sewage farming, seems to work satisfactorily wherever there is available an ample area of suitable soil, but in many cases such large areas cannot be found. In many parts of England and in some places on the continent of Europe the process is impracticable because it is impossible to get sufficient land of the right kind.

There is a certain sanitary danger in the process of sewage farming the crops grown are not properly regulated. A recent English com mission has recommended that no crops for human consumption be grown on fields used for the disposal of sewage. That is an extremely conservative position; but certainly, I think, crops should be limited to those food substances which are to be cooked before eating. The economy of the system of sewage farming is still more doubtful. It is never good policy to recover something valuable which costs more to recover than it is worth after recovery. That appears frequently to have occurred in the experience of those who have tried sewage farming, since in many instances the expenses of conducting the farms are really not paid by the crops grown on them. This does not hold good in arid regions where sewage is valuable, not only for its manurial elements, but for the water it contains; in the far West we find that the sewage farm has a most important place. The city of Pasadena, for example, has operated a sewage farm for twelve years. Alfalfa and crops of that character were grown at first with poor success, because, the crop being so near the ground, it was impossible to cultivate it properly and keep the surface open. The city is now growing mainly walnuts, with considerable profit. In 1903 the receipts from the farm were about eleven thousand dollars and the expenses about six thousand dollars, and out of the profits the original cost of buying the land is being paid off at a rapid rate. In a country of that sort the process is quite profitable, and no doubt sewage farming will have a large future in the arid regions of the West. In the East, however, where there is plenty of water, the value of the process is extremely doubtful, if for no other reason than because of the difficulty of securing economical administration under American municipal conditions.

Disposal by Intermittent Filtration.—The process of sewage purification on land soon underwent a development along more intensive lines. As early as 1865 the German engineer, Mueller, urged the disposal of sewage through land at a more rapid rate than is possible on the ordinary sewage farm. He understood the nature of the process, and knew that it was carried out by organic life; and in 1878 he patented a system "for the disinfection, purification, and utilization of sewage by the scientific cultivation of yeast-like organisms." His work, however, made no lasting impression. In 1870 the subject was approached along a different line by the English experts of the Rivers Pollution Commission under the leadership of Frankland. These experimenters failed to grasp the biological character of the process, but they understood its chemistry and showed that sewage could be successfully purified by filtration through various soils, at much higher rates than those used on sewage farms. This principle, worked out by Frankland, was applied in practice as early as 1871 by Bailey-Denton at Merthyr-Tydfil in Wales, where a filtration area was so operated as to care for 60,000 gallons per acre per day for some years.

It was only by work in this state, however, that these various lines of investigation were brought together in so conclusive a form that the importance of the process of intermittent filtration through sand was generally understood. The difficulties experienced by Worcester through the pollution by its sewage of the Blackstone River and the proposition to treat the sewage of Boston and the cities lying to the north, on the Saugus marshes, made sewage disposal an urgent question in Massachusetts in the early eighties. As a result of these conditions the Lawrence Experiment Station of the State Board of Health was founded in 1887 for the study of the sewage purification problem. There, under the leadership of Mr. Hiram F. Mills, with the coöperation of Professor T. M. Drown and Professor W. T. Sedgwick, were carried out the series of experiments since rightly spoken of as classic. Ten circular cypress tanks 17 feet in diameter and 6 feet deep were filled with various filtering materials — sand, gravel, peat, river silt, loam, garden soil, and clay. The fine materials like peat, garden soil, and clay soon clogged, but the beds of sand worked to admiration, receiving sewage above and yielding a clear, bright spring water below. Some of the original tanks have been operated from the day of their installation to the present, a period of over seventeen years, with continuously good results.

The Massachusetts investigators established very clearly that the purification was an oxidizing process, carried out by bacteria living in the sand, and that a rich supply of oxygen was necessary for their activity. In order to supply the oxygen it was necessary to dose the filters intermittently, putting on perhaps one dose a day in an amount of some 60,000 gallons per acre. These experiments led at once to the installation of a number of intermittent sewage filters in Massachusetts, and in 1903 we had twenty-three in operation in different parts of the state, the best known being those at Marlboro, Brockton, Framingham, Gardner, and Clinton; some of them have been in operation now for over ten years. It has been found that a certain amount of solid material accumulates on the surface of such beds, but the material is of a stable nature, not subject to decay, and can be scraped off at intervals and removed at some expense for labor. Cold winter weather interferes somewhat with the efficiency of the process; but by ridging the beds so that the sewage may flow in furrows under the ice, it is possible with most of the filters in Massachusetts to treat the sewage all the year round. Altogether, intermittent filtration has proved a very satisfactory method of disposal in regions covered with glacial drift, like New England, where large areas of coarse sand are easily available. When, however, you come to a country like New Jersey, where the soil is largely clay, or to many districts in England, where the soil is chalky or rocky and areas of sand are not to be found, intermittent filtration becomes almost impossible, because the cost of filters artifically constructed to operate at such low rates would be prohibitive.

The Septic Tank. — It was necessary in England to develop some new and more rapid method, and as a result three main processes have come into use. The first of these, the septic tank, is designed as a prelude to the ordinary nitrifying process. It is the logical development of the cesspool and of the *fosses fixées*, used in France by Mouras as early as 1860. The principle — that the storing of sewage without access of air led to a sort of fermentation, or ripening, which removed a considerable portion of the solid material — was patented in 1882. Scott-Moncrieff, an English engineer, in 1891 used the same process in what he called a cultivation tank, and in 1894 one was installed at Urbana, Illinois, by Professor Talbot. The process did not attain wide popularity, however, until after 1895, when Donald Cameron, of Exeter, England, gave it the picturesque name of the septic tank. Cameron's relation to the septic tank is much the same as that of the Massachusetts State Board of Health to the process of intermittent filtration through sand. As in the latter case, the principle of the liquefying tank was known before, but it was Cameron who showed the practical importance of the process. He first used a closed tank, but he soon found that this was needless; it was only necessary to allow the liquid to flow slowly through any tank, so as to have a storage of about twenty-four hours, the exact length of time varying with different sewages. Under such conditions decompositions take place, which remove from 60 to 70 per cent. of the suspended solids, turning a part into liquid form, giving off a part as gas, about 7½ gallons of gas to 100 gallons of sewage, and storing a certain amount of solids in the tank. The proportion of the solids destroyed in the tank — digested, so to speak — varies with different sewages and with the same sewage, at different times, under conditions not thoroughly understood. It was claimed at first that all the solids settled out would be liquefied in the septic tank, but this is not true; a portion only disappears, and most tanks must be opened once or twice a year for the removal of sludge.

The Contact Bed. — Meanwhile progress was being made along a different line. The chemist of the London County Council, Mr. W. J. Dibdin, undertook in the early nineties to devise some more rapid method of sewage disposal than that worked out at Lawrence. He first tried experiments in Barking, at one of the outfalls of the London system, in which he passed sewage through coke and stone in iron cylinders. Finding the process fairly satisfactory, he laid out a one-acre bed filled with coke, made tight — so that he could fill it with sewage, allow it to stand for a certain period, and then empty it. This he called the contact system, because the sewage is held in contact with the coke by the closing of the outlet. In further experiments at Sutton in Surrey, Dibdin developed the double contact system, carrying the sewage treated in one contact bed to another contact bed and treating it again. By each contact about half the impurities in the applied liquid are removed. It has been found that in the construction of contact beds almost any hard, smooth material may be used, the bed being simply a tight box for holding it. Coal and coke are particularly favorable, though stone or almost any other hard substance may be used. The size of the pieces of material, whatever it may be, varies from $\frac{1}{8}$ of an inch to $1\frac{1}{2}$ inches. The beds are commonly made from 3 to 6 feet deep, or thereabouts, but the depth does not seem to be of great importance. The sewage is run slowly into the bed, allowed to stand for a certain time, generally two hours, and then discharged, three or four fillings being made in the twenty-four hours.

The effluent from a double contact system is of good quality, so that it will not decay and can be discharged into a river with safety. The worst difficulty with the method is that there is considerable stoppage or clogging of the beds, due to settling, due to breaking down of the material, due to the growth of organisms in the bed, and partly to the deposition of solid mineral matter in its interior. Stoppage due to breaking down may, of course, be controlled somewhat by using hard material. Stoppage due to the growth of organisms can be checked to a considerable extent by a proper resting of the beds. It apparently does not tend to go beyond a certain point. The loss of capacity or clogging due to the deposition of mineral matter is more serious, and with many sewages appears to necessitate the renewal of the beds at intervals. After five years in some English plants, for instance, it has been found that the beds must all be dug over and refilled.

The process in the contact bed is a very complicated one, since it involves the alternation of two conditions, the aërobic and the anaërobic. During the full period the organic elements are absorbed by the bacterial films on the stones, and during the empty period the principal part of the purification goes on with free access of air. When the next dose of sewage enters the bed there is an entire reversal of conditions with the setting up of anaërobic fermentations, and the success of the process depends on a delicate balance between the two conditions.

The Trickling or Sprinkling Filter.—The third process developed in England was the process known as trickling filtration. In some of the early Lawrence experiments sewage was passed through rather coarse material, and air was forced in from below to check the flow and to supply oxygen for nitrification. Lowcock at Malvern in England installed a plant on this plan in 1892, and in 1894 Colonel Waring carried out experiments with a similar process at Newport, having taken out a patent on it three years before. Theoretically, this seems to be a satisfactory process for combining the necessary elements — sewage, bacteria, and oxygen — but it is almost impossible in practice to supply sufficient oxygen To insure success it would be necessary to supply from three to five times as much air as there is sewage purified.

The filtration of sewage through coarse material under continuously aërobic conditions was finally worked out, not by forced aëration, but by sprinkling the sewage over the whole surface of the filter bed in a continuous fine spray, so that the oxygen went in along with it, the sewage never filling the tank but continuously trickling through the filtering material. A filter of this type made of broken chalk was first built by Stoddart in 1893 and exhibited by him at Bristol in England. Meanwhile Corbett, of Salford, had worked out a similar idea; Scott-Moncrieff, Ducat, and others contributed to the development of this type of purification. One of the advantages of the trickling bed system is the extreme simplicity of its construction. It is only necessary to have a heap of material over which the sewage can trickle. It needs, of course, some kind of floor sloped to carry off the drainage, but aside from that the material used can be held together by wooden palings, or iron bands, or any very simple structure around the outside. The depth is generally 4 feet or over, and, as in the case of the contact bed, any hard material may be used, varying in size from $\frac{1}{8}$ inch to $1\frac{1}{2}$ inches.

The most serious difficulty is in regard to the distribution of the sewage. It must be so applied as to pass through slowly and well mixed with air. Colonel Ducat used tipping buckets, a series of triangular troughs which discharged at intervals, splashing little dashes of sewage over the surface. Stoddart used a trough, from which the sewage overflowed continuously, dripping off from numerous points below; this was good in theory, but difficult to keep working in practice, because the troughs buckle and any difference in level prevents an even distribution. At Salford they used sprays with fixed pipes, like a series of fountains, and many of the English plants are equipped with complicated revolving mechanisms like lawn sprinklers. The most cumbrous of all these contrivances is a radial carrier which moves round and round the bed, its extremity revolving on the wall at the periphery, — dripping sewage as it goes. The rates which may be obtained by the trickling process are very high. The sewage farm will take perhaps an extreme of 10,000 gallons, the intermittent sand filter perhaps 100,000 gallons, and the contact bed 500,000 or 600,000 gallons per acre per day; the trickling filter, on the other hand, easily treats 2,000,000 gallons per acre per day, giving an effluent on the whole better than the contact bed, though not so good as the sand filter. It contains a considerable amount of suspended solids, and does not look as clear as the effluent from the contact bed. But the effluent analyzes well and keeps well, which are the principal points to be considered. Furthermore, its solids may be easily removed by a short period of sedimentation.

Progress in England. — The early English results on what are called the biological methods — although the intermittent filter is a biological method, the name has been particularly applied to the contact and trickling systems — led first to the construction of contact beds. At Exeter, for example, the double contact system was installed. At London it was recommended that the sewage should be treated in septic tanks and single contact beds, although the plant has not yet been begun. At Manchester, experiments in 1899 led to the recommendation of septic tanks, with double contact beds; and forty-eight acres of first contact filters are already in operation. The second contact beds have not yet been built, and the work of the primary filters has not been altogether what was hoped. The next important experiments were carried out at another great manufacturing centre, Leeds, and there the contact system received a setback. It was found that the beds clogged so badly, with so great a loss of capacity, that the cost of renewal would be prohibitive. By the use of the trickling filter, however, the sewage could be well purified, and the installation of trickling filters has been planned, though not yet executed. At Birmingham the problem was next attacked, and the experts came to the conclusion that the trickling filter is best adapted to local conditions; construction has already been begun. At the present time, while the sewage farm exists in a number of English cities, no new ones are likely to be laid out and the old ones will be gradually abandoned, in all probability. The tendency now is toward the installation of septic tanks and trickling filters. The tide may change again in a few years more, but at present these are the popular systems in English practice.

European Practice. — In Germany progress in sewage treatment has been very slow, much slower than in England. The problem has not pressed so hard, the population being less dense and the rivers larger. It has been possible, as a rule, where sewer systems exist to discharge the sewage directly into streams. Some admirable work has indeed been carried out at the Hamburg Testing Station, under Dr. Dunbar, particularly with relation to the theory of the action of the contact bed; and within the last four years a testing station has been founded in Berlin which has yielded important results. As yet the septic tank has not found favor in Germany — whether on account of carelessness in operation, or on account of the large amount of industrial waste materials in the sewage, is not quite clear. In the use of the contact system it has been found necessary to renew the beds quite often, even once or twice a year, a necessity which the German engineers appear to regard with equanimity. The trickling filter is just beginning to be known, and at Berlin is awakening some enthusiasm. Progress in Germany has only followed that in England; and on the rest of the continent practically nothing has been done except in the line of sewage farming. French engineers have recently visited England and carried home news of the biological experiments; but that is practically all.

Conditions in the United States. — In the United States the problem is a diverse one. As in the case of water purification, local conditions in different parts of the country must be met by totally different methods. Here in Massachusetts the intermittent filter is perfectly satisfactory, and probably will be used for a long time to come. West of the Alleghanies it is often impossible to install such filters, because the required areas of sand are not available. In the Middle West we generally find the septic tank combined with the sand filter, because it is thus possible to treat the sewage at higher rates. Contact beds and one or two interesting trickling filters have been installed in these regions. The question of sewage purification in the Middle West will largely be controlled by the results of the experiments just completed at Columbus. Columbus is the first American city — the Lawrence Station being, of course, a state institution — to approach the subject of sewage purification in a rational way. It bids fair to be the model sanitary city of the country, with unique and interesting systems of sewage disposal and water purification, and probably a fine garbage disposal plant as well. About a year ago the city called in Messrs. Hering and Fuller to investigate and report on the best method of sewage treatment, and appropriated nearly fifty thousand dollars for experimental work. A fine experiment station was equipped, in which studies were made of over forty separate methods of disposal. The experts have finally reached the conclusion that the best treatment for Columbus sewage is by the use of the septic tank, followed by the trickling filter and this again by sedimentation; and they are now proceeding with the construction of what will be the largest plant in the country, including ten acres of trickling filters. This will surely lead to the construction of numerous similar plants in regions where conditions are similar to those at Columbus.

Experiments at the Technology Experiment Station.—At the Sewage Experiment Station connected with the Massachusetts Institute of Technology experiments on the treatment of Boston sewage were begun a year before those at Columbus, but we are prepared at present to make only a preliminary report. We found, in the first place, that the sewage of the South Metropolitan District is a fairly strong city sewage — a sewage from a city sewered on the combined system, which receives street washings as well as household waste — peculiar only in that it contains a somewhat large amount of suspended matter and considerable sea water, which backs up through leaking tide gates. The first problem which always confronts the engineer in the disposal of sewage is the question of the removal of solids, and it is necessary to distinguish between two or three kinds of solids. In the first place, there are large floating objects, such as rags, bits of wood, etc., which must always be removed by screening. In the next place, we find rather coarse mineral matter, gravel, etc., from street washings. This will settle out quite readily if, for example, the flow be checked to half a foot per second for a very few minutes. Material of this sort, which we call detritus, must always be removed in any system. It is almost entirely inorganic, of such a nature, therefore, as not to require purification. We have spread the detritus removed at our Albany Street Station during the whole period of experimentation, in the yard of the station without causing a nuisance. When, however, you consider the more finely divided matter, organic in nature, which will settle out only if you reduce the flow to one-tenth of a foot per second for several hours, the difficulty becomes more serious. This finely divided suspended matter may be removed in several ways. The old method for its removal was to treat the sewage with chemical precipitants, but the chemicals are costly and increase the amount of sludge to be handled; only in exceptional cases is that method now used. In such cities as Worcester, where the sewage contains large amounts of certain industrial waste materials, which hinder the biological process and favor the chemical process, precipitation is useful; but from a general consideration of the problem chemical treatment may be dismissed. There are, then, besides the use of chemical precipitants three alternatives with regard to the organic suspended matter. You may either leave it in the sewage to be treated afterward in the contact or trickling filter or sand bed, or you may take it out by plain sedimentation or by the septic tank. The difference between plain sedimentation and the septic tank is simply that in the septic tank the flow is continuous; the tank is not emptied, and the accumulation that settles out is maintained in contact with the material that flows over it. The removal of the sludge is due always to sedimentation. In the septic tank you store the sludge after removing it, and allow the bacteria to liquefy a part. That might seem a clear gain in the use of the septic tank as compared with plain sedimentation; and the septic process certainly disposes of a certain portion of the sludge by liquefaction, the amount varying with the special sewage treated. Furthermore, the actual removal of solids from the effluent is probably greater, from the liquefaction of particles too fine to settle out. The idea that a favorable action on soluble matter is exerted in the septic tank which makes the later nitrifying process easier is very doubtful. There is no evidence of any favorable action; there is, on the other hand, evidence that the septic process may exercise an unfavorable action on the sewage, producing poisonous substances which interfere with proper oxidation. At Andover in this state it has been found more difficult to treat sewage which has been septicized than crude sewage. In our own experiments we have found that sewage which has been septicized is much more difficult to handle than crude sewage. This appears to be largely due in our case to the presence of calcium sulphate from the sea water, which decomposes in the septic tanks and forms harmful compounds of sulphur. Such a condition must occur, not only in marine cities, but in some inland cities where there are hard waters. We are not quite prepared to say that the septic tank cannot be used in some form with Boston sewage. It may be possible by limiting the action to a brief period, or by subsequent aëration, to avoid hampering the nitrifying bacteria. Along those lines we are still experimenting.

The third alternative to septic treatment or sedimentation is to put the sewage directly on the nitrifying beds, whether contact, sand, or trickling filters. The tendency in England is almost entirely against any such action. They think there that the septic treatment or very thorough sedimentation is absolutely necessary, and, indeed, with many sewages it is. Personally, I do not believe it is safe to say that it is necessary with all sewages. There is no doubt that if you do not do it you will get sludge in your sand bed, contact bed, or trickling filter, and that will sometimes necessitate the renewal of filtering material. Also, there is no doubt that sludge is much harder to remove from the contact or trickling bed than from the septic tank. But, on the other hand, there is some evidence that the sludge is very much less in amount in the contact or trickling bed than in the septic tank, because the oxidizing processes going on in the tank consume a large proportion. The difficulty of sludge removal from the contact bed or trickling filter must be balanced against the cost of the installation and operation of the septic tank or sedimentation basin. Only experimentation in each particular case will determine what method is most desirable for the sewage in hand.

Disposal of Boston Sewage. — With regard to final purifying processes, we have found in our experiments that crude Boston sewage can be treated in sand filter beds at quite a high rate, at the rate of 400,000 gallons per acre per day. That rate, of course, is higher than could be attained in practice, because in our small experimental tanks we can get the sewage distributed very evenly over the surface of the beds, and because they are protected from the severity of winter. We are anxious, however, that the attempt should be made with filters in actual operation to use higher rates than are now common on sand filter beds. We are inclined to think that the sand filter has never been pushed quite as hard as it might be. Of course, with higher rates you get more sludge on the surface, which will mean more costly operation. But it is a question whether it will cost much more to get 200,000 gallons through one acre than to get 200,000 gallons through two acres. With double contact beds we have found it possible to treat Boston sewage at a combined rate on two beds of 700,000 gallons per acre per day. Clogging occurs, which would probably render renewal of the first contact beds necessary at intervals of three or four years. Either of these methods would prove extremely costly for so large a city as Boston.

In regard to trickling beds, our experiments have not yet been carried far enough to get definite results. With that particular process it is necessary to work on a large scale and out of doors; so during the past summer we have constructed an out-of-door trickling filter, which will take 10,000 gallons of sewage in the twenty-four hours at the rate of 2,000,000 gallons per acre per day. The English results have shown, as I have already said, that the trickling filter can treat sewage at much higher rates than other processes, giving a very satisfactory effluent, and that the body of the beds is cheaper to construct. On the other hand, the difficulties are two — the distribution of the sewage and the possible bad effect on the beds of the severe winter climate in this country. The question of distribution is a very serious one. In Columbus they use a system of buried pipes, with sprinkler heads at intervals to spray the sewage over the beds. In our filter the sewage drops from a wooden trough into metal cups, and splashes from them over the bed. This, we think, is simpler than any other device in use, and we hope will not be as seriously affected as some others by the climate. At present, engineers need to develop a cheap and practical system of distribution, and need more light as to the effect of a severe winter climate on trickling beds with various types of distributers. If those two problems can be solved it seems that the trickling filter furnishes the best treatment of sewage known. If it is necessary to produce the very highest purification, the turbid effluent from this type of bed may be settled and sterilized by copper or some other process, or may be strained rapidly through sand. In that way it is perfectly easy to make a bright, clear effluent at no very high cost. The trickling bed appears to be the ideal method for solving the essential problem of sewage disposal, the oxidation of organic matter. It exhibits the simplicity of all scientific applications, which are merely intelligent intensifications of natural processes. A pile of stones on which bacterial growth may gather and a regulated supply of sewage are the only desiderata. We meet the conditions resulting from an abnormal aggregation of human life in the city, by setting up a second city of microbes. The dangerous organic waste material produced in the city of human habitations is carried out to the city of microbes on their hills of rock, and we rely on them to turn it over into a harmless mineral form.

EXPERIMENTS ON THE PURIFICATION OF BOSTON SEWAGE, 1903-1905

By C.-E. A. Winslow and Earle B. Phelps,
OF BOSTON, MASS.

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INTRODUCTORY.

The Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology was established by a friend of the Institute for the purpose of making experiments and promulgating information with regard to the scientific disposal of sewage, especially the sewage of large cities.

The laboratory and station are situated in the southeasterly part of the city of Boston, near the corner of Massachusetts Avenue and Albany Street. Connection is made by a two and one-half inch iron pipe and suction hose with the nine-foot sewer of the Boston main drainage system at a point on Massachusetts Avenue, about 200 feet below the entrance of the Albany Street intercepting sewer. Prior to October 14, 1904, sewage from the whole of Boston south of the Charles, with the exception of the Dorchester and South Boston districts, together with sewage collected by the South Metropolitan sewerage system, from Waltham, Newton, Watertown, Brighton and Brookline flowed past the station intake. In 1903-04 the flow at the station was above fifty million gallons a day from a district with a contributing population of 350,000, sewered for the most part on the combined system.

The sewage, drawn from the sewer by a 4 by 6 duplex Warren power pump, passes through a grit chamber made of an iron casting 16 inches deep and 19 inches in diameter, with a central screen having one-half inch openings. Here the velocity of the sewage is checked to .04 feet per second for about 45 seconds. The sand and other detritus taken from this chamber amounted in sixteen months to 4,800 pounds of wet material or .65 cubic yards per million gallons of sewage. Analysis indicated that the 4,800 pounds of detritus contained 1,300 pounds of water, and only 319 pounds of organic matter. As a whole the material was of an innocuous character, and during the whole course of our experiments it was spread out on the land adjoining the station without producing any nuisance.

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* Preliminary Abstract.

THE CRUDE SEWAGE.

The average yearly results of almost daily analyses of the crude sewage as it reached the station after passage through the grit chamber are given in Table I.

TABLE I.

COMPOSITION OF BOSTON SEWAGE.

Parts per million.

No. of Samples.	Date.	Turbidity.	Temperature.	Nitrogen as						2 minutes boiling. Oxygen Consumed.		Oxygen dissolved.
				Alb. Ammonia.			Free Ammonia.	Nitrites.	Nitrates.			
				Total.	Solution.	Suspension.				Total.	Soluble.	
102	June '03–June '04.	.....	60	6.33	3.11	3.22	19.7	0.27	0.06	45.2	22.5	2.8
159	June '04–June '05.	305	58	5.67	2.96	2.71	17.6	0.14	0.12	41.5	24.6	2.2

The organic constituents of the Boston sewage are quite normal in their relation to one another. Regular determinations of the organic nitrogen were not made, but judging from the average of some fifty such determinations made at various times in the course of experimental work, it may be stated that the organic nitrogen figures for the whole period average about 20 parts per million. In this respect the sewage appears to be about the same strength as the average sewage of Massachusetts cities, being slightly weaker than the sewages of Lawrence and Gardner (new system), and somewhat stronger than the sewages of Framingham, Worcester and Brockton.

The inorganic analysis of mixed weekly samples which covered the calendar year 1904 showed 2,300 parts per million of chlorine, 15 parts of iron, 125 parts of alkalinity as calcium carbonate and 220 parts of SO_3 as sulphates.

The high chlorine and suphate values are due to the large amount of sea water present in the sewage of Boston. Assuming the chlorine, normal to the sewage itself, to be equal to the total nitrogen, a simple calculation shows that the amount of chlorine present represents a volume of sea water equal to 11 per cent. of the total volume of the sewage. This, however, is only an average value for the period.

During each twelve hours the chlorine reaches a maximum figure of from 3,000 to 4,000 parts per million, representing 19 per cent. of sea water, while between these maxima there are minimum points of about 200 parts per million representing only one per cent. of sea water. It may be an important question in any project for the purification of Boston's sewage whether the extra cost of pumping and treating this amount of sea water might not be greater than the cost of keeping it out of the sewers. In this connection it might also be well to consider the possibility that a large amount of sea water, saturated as it is with oxygen, may be of actual advantage in any aerobic process of treatment.

The suspended solids, amounting to some 300 parts per million, are considerably higher than the average for American sewages.

THE SEPTIC TANK.

Assuming that if any preliminary treatment were necessary in the purification of Boston sewage, the septic tank would probably furnish the most available method, the next problem was to determine the best conditions under which a septic tank could be operated. In particular we desired to compare the efficiency of different periods of storage, the results obtained from open and closed tanks and the effect of filling a tank with stone in order to increase the amount of surface action.

Our experiments were carried out in six cypress tanks, each 6′ x 4′ x 3′ deep. Tanks 7 and 9 were open. Tanks 5, 6, 8 and 10 were closed in with tight planking, Tank 6 was filled with 1½″ crushed stone. The rate and the average analysis for each effluent are shown in Table II.

TABLE II.

ANALYSIS OF CRUDE SEWAGE AND SEPTIC EFFLUENTS.

General Averages.

(Parts in 1,000,000.)

	Date.	Storage Period. (Hours.)	Turbidity.	Temperature.	Nitrogen as				Oxygen Consumed. 2 minutes boiling.	
					Alb. Ammonia.			Free Ammonia.		
					Total.	Solution.	Suspension.		Total.	Soluble.
Sewage	June 1903–June 1905.		305	59	5.94	3.02	2.92	18.5	43.1	24.4
Sewage	Mar. 1904–June 1905.		305	58	5.66	2.97	2.65	17.6	41.5	24.7
Tank 5	June 1903–June 1905.	48–12*	200	57	3.80	2.64	1.16	20.7	36.9	26.9
Tank 6	June 1903–June 1905.	24	175	57	3.41	2.52	0.89	21.5	37.8	26.0
Tank 7	Mar. 1904–June 1905.	12	170	55	3.37	2.50	0.87	17.6	33.2	27.9
Tank 8	June 1903–June 1905.	48	190	57	3.84	2.58	1.26	22.1	40.7	29.9
Tank 9	Mar. 1904–June 1905.	24	170	55	3.24	2.43	0.81	19.4	34.1	27.5
Tk. 10	June 1903–June 1905.	24	210	56	3.77	2.53	1.24	22.5	37.5	24.5

* Changed December 7, 1903 from 48 hours to 12 hours.

Septic action began in all the tanks very soon after they were started, the effluent being free from gross turbidity and much darkened. The dark color and offensive odor of the septic effluents are undoubtedly due in part to the formation of sulphides from the sulphates introduced in the sea water. Scum formed at first on the open tanks, but later disintegrated and sank without reforming. In the closed tanks a scum an inch thick was found when they were finally opened.

Inspection of Table II shows that the septic tanks reduced the total albuminoid ammonia to from two-thirds to one-half its sewage value. The diminution of dissolved albuminoid ammonia was slight but distinct, while the suspended portion was reduced to a little over one-third its original amount. Comparison of the different effluents shows a remarkable uniformity of results. In comparing tanks 5 and 10 (closed) with the corresponding 12 and 24 hour open tanks, the open-tank effluents appear to be slightly better. It must be remembered, however, that the open tanks were operated during the last fifteen months only, when the sewage was weaker. Taking this factor into account the work of the open and closed tanks is practically equal.

With regard to period the figures are no more conclusive. Comparing tanks 7 and 9 (open), there appears to be no important difference between the effect of 12 and of 24-hours' storage. Similarly, tanks 5, 8 and 10 (closed) produce almost the same results, although operating with periods varying from 12 to 48 hours. The length of the storage period seems therefore not to be a matter of great importance. Tank 6, with 1½" crushed stone, produced a somewhat greater reduction in suspended albuminoid ammonia than did the other tanks; but the difference is too slight to be of great practical importance.

When this series of experiments was closed in June, 1905, the inlet and outlet of each tank were closed and the contents, including scum and sludge, thoroughly stirred. Samples of the suspension thus produced were then analyzed in order to gain an idea of the material which had accumulated during the whole period of operation. From the results we have calculated, in Table III, the actual amounts of certain constituents which were (*a*) allowed to enter the tanks, (*b*) discharged in the effluents, (*c*) stored in the tanks as sludge and scum, and (*d*) removed by septic decomposition. About 50 pounds of nitrogen as albuminoid ammonia per million gallons of sewage entered the tanks; 30 pounds, roughly, were discharged and 20 pounds remained behind, of which from 15 to 17 pounds were decomposed. The last columns in the table show the total volatile solids and fats stored in the various tanks calculated in relation to the sewage treated. These figures bring out very sharply the superior decomposing power of the tanks operated at short periods. Tank 7 (12 hours) and tank 5 (12 hours for the last eighteen months) show the lowest values. Tanks 9 and 10 (24-hour period) come next, with 90 and 101 pounds respectively. Tank 8, with its 48-hour period, stored 206 pounds of organic matter per million gallons of sewage treated. The large proportion of fats indicated in the last column is notable, amounting as it does to one-fourth or one-eighth of the total stored organic matter.

Altogether we may conclude from our experiments that the septic tank will effect a considerable removal of solids from Boston sewage, amounting to some two-fifths of the nitrogen as measured by albuminoid ammonia. Its effluent is free from gross turbidity, but dark and offensive from the liberation of hydrogen sulphide. Of the organic matter retained in the tank a very large proportion, amounting to well over three-fourths if measured by the albuminoid nitrogen, is decomposed and the accumulation of stored material in the tank is slight after two years of operation. Apparently such tanks might operate for several years without being cleaned. The covering of tanks is immaterial since closed and open tanks work equally well. Storage periods, varying from 12 to 48 hours, give similar effluents, but there is an increasing tendency to accumulate sludge as the period is lenghtened. This, may probably be due to the accumulation of harmful bacterial products which check the liquefying organisms. The filling of a septic tank with stone is of only slight advantage.

TABLE III.

STORAGE AND DECOMPOSITION OF ORGANIC MATTER IN SEPTIC TANKS.

(Pounds per million gallons.)

	Flow. (Gallons.)	Storage Period. (Hours.)	Nitrogen as Albuminoid Ammonia.				Solids Loss on Ignition Stored.	Fats Stored.
			Entering.	Leaving.	Stored.	Decomposed.		
Tank 5.............	445,000	48-12*	49.2	31.7	1.3	16.9	69.0	16.2
Tank 6.............	135,000	24	49.2	28.3	10.1	11.9	......	101.
Tank 7.............	393,000	12	46.7	28.3	.4	18.1	35.3	6.3
Tank 8.............	133,000	48	49.2	31.7	2.6	15.9	206.	29.3
Tank 9.............	197,000	24	46.7	26.7	1.5	17.8	89.7	25.0
Tank 10............	266,000	24	49.2	31.7	1.6	17.3	101.	15.3

* Changed December 7, 1903, from 48 hours to 12 hours.

THE INTERMITTENT SAND FILTER.

The sand filters studied were cypress tanks, 6′ x 4′ x 3′ deep. Over 6″ of underdrain material, graded from 3″ stones down, was a layer of drift sand of an effective size of .14 mm. and a uniformity coefficient of 3.5. The sand in tank 2 was one foot deep and in tanks 1, 24 and 25, two feet deep. Tanks 1 and 2 were dosed with crude sewage, tank 24 with 12-hour septic effluent, and tank 25 with 24-hour septic effluent. The rate on tanks 1 and 2 was at first .1 million gallons per acre per day, but on tank 1 it was gradually worked up to .4 million gallons per acre per day, the daily dose being divided into four portions, applied at six hours' intervals.

These experiments gave quite conclusive results as to the minimum depth for a sand filter. Tank 2, with its one foot of depth, proved a complete failure. Its effluent was dark and turbid, and offensive in odor. Not one of the samples tested passed the incubator test. The analytical results showed marked variations from time to time, but the free ammonia present was generally from 15 to 20 parts per million, nearly as high as the crude sewage. The albuminoid ammonia was usually between 2 and 3 parts, and the oxygen consumed in the neighborhood of 20 parts, in each case about half the sewage value. Nitrates were always low.

The operation of the other beds, on the contrary, was eminently satisfactory. All three effluents were clear and bright, entirely free from turbidity and odor and stable by the incubator test. The average analyses in Table IV show that the effluent from the treatment of crude sewage was slightly better than that produced by the treatment of septic effluent. The increase in rate on tank 1 from .1 to .2 and again from .2 to .4 did not appreciably alter the quality of its effluent.

TABLE IV.

ANALYSIS OF SAND FILTER EFFLUENTS.

(Parts per million.)

Tank.	Receiving.	Nitrogen as				Oxygen Consumed. 2 min. boiling.	Oxygen dissolved.
		Free Ammonia.	Alb. Ammonia.	Nitrites.	Nitrates.		
1	Crude sewage	4.2	.6	.4	22.3	5.6	6.1
24	12-hour septic effluent	5.0	.8	.3	19.9	6.5	7.5
25	24-hour septic effluent	5.6	.9	.2	16.0	6.5	7.2

The surface of the filters, even at such high rates, did not require undue care. Tank 1 was scraped in August, 1903, and November, 1904, and raked once and scraped once in March, 1905. The total material removed in three scrapings during two years of operation, amounted to a layer .48 inches in thickness or 1,600 cubic inches. The filters taking septic effluents showed still more favorable results During their fifteen months of operation tank 24 was raked over twice and scraped once, while tank 25 was raked over once and never scraped.

In general our results indicate that in reducing the depth of a sand filter it is not safe to go below 2′. A single foot of sand is insufficient to produce purification, while a two-foot bed may yield admirable results. With regard to the value of preliminary septic treatment of Boston sewage before sand filtration, it appears that effluents from the combined process are slightly inferior to those obtained by the sand process alone, while the care of the surface is more difficult when crude sewage is treated. We believe our experiments indicate that it may be possible to treat crude sewage by sand filtration at higher rates than have heretofore been recommended. We are aware that the operation of filter beds under practical conditions is much more difficult than in such experiments as ours, on account of imperfect distribution and the detrimental effect of severe weather conditions. Yet we believe that our results suggest the possibility of operating sand filters, with proper care and the application of several doses of sewage during the twenty-four hours, at higher rates than those commonly in use.

THE CONTACT BED.

The experiments on contact treatment were made in cypress tanks four feet square, four being four feet deep and five, six feet deep. Of the six foot single-contact beds, two were filled with ½″ broken stone, one with 1″ broken stone, one with 1½″ broken stone and one with 2″ coke. During the second year the one-inch tank was emptied and refilled with facing bricks, laid in even tiers after the pattern of Dibdin's multiple-surface bacteria bed. The four-foot double contact beds were so arranged as to give two primary beds of 1½″ stone, and two secondary beds of ½″ stone. One pair took crude sewage and the other pair septic effluent, which had received thirty hours' treatment.

In each case the mode of operation was as follows: the bed was filled during the course of an hour, allowed a two-hours' contact period, emptied in about half an hour and allowed to stand empty till the next filling. All the beds were started with one filling a day. In August, 1903, the rate on four of the single contact beds was increased to two fillings and that on the fifth to three fillings a day. The higher rate seemed to give better results so in January, 1904, the rate on the four beds was again increased to four fillings. This proved somewhat too strenuous, however, and since June, 1904, all the beds, single and double alike, have received three fillings in the twenty-four hours.

Capacity measurements were made on each bed once a week by discharging the effluent into a measuring tank. The initial liquid capacity varied from 39 per cent. to 48 per cent., the highest values, of course, being found in the brick and coke beds. The single contact beds taking crude sewage all decreased in capacity quite steadily, reaching a final value, after two years, of 26-33 per cent. The Dibdin brick filter still showed 40 per cent. open space after one year of operation. The first contact bed receiving septic effluent, and both second contact beds, maintained capacities of over 35 per cent. The loss of capacity was made good to some extent by resting.

The average analyses of the effluents from the various beds are brought together in Table V.

TABLE V.

GENERAL AVERAGE. ANALYSES OF CONTACT FILTER EFFLUENTS.

(Parts in 1,000,000.)

Filter.	Date.	Material.	Size of Material	Average Rate.	Turbidity.	Temperature.	Nitrogen as						Oxygen Consumed. 2 minutes boiling.		Oxygen dissolved.	Capacity.	
							Alb. Ammonia.			Free Ammonia.	Nitrites.	Nitrates.					
							Total.	Solution.	Suspension.				Total.	Soluble.		Initial.	Final.
Tank 11	June '03–June '05.	Coke	2 ″	1.8	130	57	3.16	2.17	0.99	18.9	.45	1.08	22.1	15.5	0.50	46	32
Tank 12	June '03–June '05.	Stone	1½″	1.4	130	57	3.15	2.12	1.03	17.6	.52	1.34	25.3	16.3	0.40	40	30
Tank 13	June '03–June '05.	Stone	½″	1.2	55	56	1.96	1.45	0.51	11.0	.69	7.22	14.3	9.8	1.37	44	33
Tank 14	June' 03–June '04.	Stone	1 ″	1.4	155	57	3.56	2.43	1.13	20.0	.49	0.04	28.3	14.0	0.36	42	...
Tank 14A	June '04–June '05.	Brick	......	2.0	195	57	3.89	2.38	1.51	16.4	.23	0.38	27.5	20.4	1.42	48	40
Tank 16	June '03–June '05.	Stone	½″	1.2	65	58	1.73	1.34	0.39	8.1	.83	9.80	13.1	9.6	1.28	42	30
Tank 17*	June '03–June '05.	Stone	½″	1.2	80	55	2.26	1.70	0.56	15.5	.35	5.20	16.9	11.7	0.55	39	35
Tank 18*	June '03–June '05.	Stone	½″	1.1	80	57	2.11	1.49	0.62	11.5	.67	8.60	16.1	12.4	1.25	42	37
Tank 19†	June '03–June '05.	Stone	1½″	1.2	155	56	3.33	2.28	1.05	20.9	.21	0.91	28.0	19.0	0.38	41	38
Tank 20	June '03–June '05.	Stone	1½″	1.1	120	57	3.64	2.48	1.16	15.4	.50	4.01	22.4	15.4	0.84	41	26

* Second contact beds. † Receiving septic effluent,

With regard to kind of material, a comparison of tank 11 (2" coke) with tank 12 (1½" stone) shows that the effluent of the former was slightly better than the latter, in spite of the larger size of the material and the higher rate.

On the more important question of the size of material, a comparison of tank 12 (1½" stone), tank 13 (½" stone) and tank 14 (1" stone) is instructive. The effluents from the 1" and 1½" stone were never of satisfactory quality except, in the latter case, at the very end of the experiment, while that from the ½" stone was generally clear and non-putrescible. The result in this case was only reached, however, at the expense of a serious clogging which necessitated the removal of four inches of sludge from the surface during two years of operation, leaving the body of the filter for some way below the surface still badly clogged. These results correspond with those obtained by Dunbar and other German investigators. They show that with beds of fine material a good effluent may be obtained by a single contact, but at the cost of such clogging as to necessitate somewhat frequent removal of the upper portion of the bed.

Data bearing on the effect of contact beds of different depths may be obtained by comparison of tanks 12 and 20. Both were filled with 1½-inch stone and dosed with three fillings a day of crude sewage. The depth was six feet for tank 12 and four feet for tank 20. It is apparent that the results of treatment in the four-foot bed are consistently better than in the six-foot bed. In particular it will be noticed that the nitrification is more complete in the shallow filter; but the difference is scarcely great enough to compensate for the diminished rate.

A comparison of the double contact systems, 17 and 19, and 18 and 20, furnishes interesting results with respect to the value of preliminary treatment. The primary beds were both 4' tanks filled with 1½" stone. It will be noticed that the effluent of tank 20, which took crude sewage, was markedly superior to that of tank 19, dosed with septic effluent, except, for part of the time, in its albuminoid ammonia content. The effluent from tank 20 was often non-putrescible while that from tank 19 was always foul and offensive. As pointed out above, the septic treatment was efficient in preventing clogging, the final capacities of tanks 19 and 20 being 34.6 per cent. and 26.5 per cent., respectively. This advantage is, however, dearly bought, since the septic effluents from Boston sewage evidently contain substances inimical to bacterial action which seriously interfere with subsequent purification. Even the secondary filter effluents showed the same deleterious effects. In nitrogenous constituents and in available oxygen, the effluent of tank 18 was better than that of tank 17. The former was clean and stable, the latter generally dark colored and smelling of hydrogen sulphide.

In general it appears that a single contact treatment will remove from one-third to one-half of the organic constituents of sewage with the production of an improved but still putrescible effluent. Beds of ½" stone form an exception to this rule, since after a time they may yield a stable effluent, but at the cost of very serious surface clogging.

Secondary contact treatment effects a removal of one-third to one-half of the remaining organic matter, producing a satisfactory effluent in the case of the treatment of crude sewage. Preliminary septic treatment for thirty hours, although it maintains the capacity of the beds, exerts a detrimental effect in the treatment of Boston sewage, producing an effluent hard to purify even by the double contact system. The possibilities of septic treatment before contact filtration can not be considered as exhausted, since we have only tried rather old septic sewage (30 hours), without any special method of aeration.

CONCLUSIONS.

It will be necessary in any treatment of Boston sewage to screen out large floating bodies and to settle out mineral detritus. In our judgment, this process should be limited to a sedimentation of a few minutes. Under such conditions the settled material amounts to some 1,600 pounds per million gallons of sewage, and is of such a character that it may be spread out on land without fear of nuisance.

A further removal of the suspended organic matter may be effected if desired by treatment in the septic tank. An open tank operates just as well as a closed one, and there is no marked advantage in filling the tank with stone. Varying the storage period from 12 to 48 hours produces no difference in the effluents which is measurable by analytical results. All our tanks removed nearly two-thirds of the suspended albuminoid nitrogen and produced an effluent fairly free from suspended matter, but much darkened by hydrogen sulphide. The tanks on an average received 50 pounds of nitrogen as albuminoid ammonia (dissolved and suspended) of which 30 pounds were discharged in the effluent, 15-17 pounds were decomposed and 3-5 pounds were stored as sludge. In the decomposition of sludge, the length of the septic period is of great importance. The amount of organic solids stored, undecomposed, per million gallons of sewage passed, is twice as great with a 48-hour period as with a 24-hour period and four times as great as with a 12-hour period.

Under the conditions of our experiments, crude Boston sewage has been successfully filtered through a two-foot bed of sand, with an effective size of .14 mm., at a rate of .4 million gallons per acre per day, divided into four doses in the twenty-four hours. We should not expect such high rates in actual practice, but we do believe that with care in construction and operation the sand filter may be efficient at higher rates than has been generally recognized. The effluents obtained from our sand beds were clear and bright and well purified. The depth of the beds can not safely be reduced below 2 feet. Preliminary septic treatment for 12 or 24 hours does not improve the effluents obtained with sand filtration, although it makes the care of the surface of the beds somewhat easier.

Crude Boston sewage may be treated in single contact beds of fine stone (one-half inch diameter) at a rate of about 1.2 million gallons per acre per day. The effluent is only partially purified, although generally so stable as to be discharged into water without any tendency to create a nuisance. The beds clog rapidly and the surface needs much attention. The double contact system of treatment in primary beds of 2″ material and secondary beds of ½″ material would yield a fairly well purified and stable effluent at a rate on the combined double system of about .7 million gallons per acre per day with beds 6′ deep. Such a system clogs somewhat, and would require resting and renewal at frequent intervals. Preliminary septic treatment for thirty hours enables the beds to maintain a higher capacity but produces an effluent which, without special aeration, is so difficult to purify that their efficiency is seriously interfered with. The most practical method of those which we have studied would appear to be the treatment of sewage, either sedimented or subjected to a very short period of septic action in double contact beds. The process of trickling filtration remains to be considered in a further report.

[Reprinted from TECHNOLOGY QUARTERLY, Vol. XVIII, Nos. 1 and 2, March and June, 1905]

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE INTERPRETATION OF A SEWAGE ANALYSIS

BY EARLE B. PHELPS

(Received February 1, 1905)

It is often the case that analytical data express to the mind of the analyst the direct information desired, but at times there are cases in which such figures convey no useful information until they are examined in the light of past experience. For example, in an assay of a gold ore the results require no explanation, but the results of a steel analysis convey to the lay mind only the idea that there were present in the steel certain very small amounts of sulphur, carbon, phosphorus, etc. To the expert, however, these figures of the steel analysis stand clearly and definitely for certain marked properties in the steel.

This expression of analytical data in terms of physical or other properties of the substances analyzed is called an interpretation of an analysis.

In the case of sewage there are, unfortunately, no well-marked physical characteristics such as are found in steel with which our analytical data may be compared. The interpretation of a sewage analysis is largely a matter of experience on the part of the analyst, or of reference to other analyses for the sake of comparison, rather than any concrete reference to definite properties. Nevertheless when sewages are spoken of as "strong domestic," or "typical city," it is doubtful if any analyst could, from these descriptions, satisfactorily reconstruct the essential features of the original analyses.

In view of the fact that important steps are being taken just now toward standardizing and unifying our methods of analysis, it has seemed to the writer that a brief discussion of our present knowledge of the chemistry of sewage, so far as it relates to the routine analytical procedure, might not be out of place. To attempt to place the interpretation of a sewage analysis upon the same plane as that of a steel analysis would, of course, be out of the question. It would seem, however, that we have already at hand sufficient analytical data to warrant us in an attempt at correlating this material with the more important variable characteristics of the sewage. It will be necessary first to define these characteristics, keeping in mind the fact that they must be, first, variable and correlated with the analytical data, and, second, of sufficient importance in the ultimate problem of sewage treatment to warrant their study.

These characteristics in a sewage are three in number: the physical property of concentration; the chemical property of composition; and the biological property, which I will call condition.

First in importance is the concentration of the sewage, or, more accurately, of the dissolved and suspended matters in the sewage. By this factor one does not mean merely the concentration as determined by the total solids. For a thorough understanding of the processes of sewage purification the concentration of the organic nitrogen, organic carbon, fats and fatty bodies, and, to a lesser degree, of the various mineral constituents should be known.

Hardly second in importance is the chemical characteristic or composition of the sewage. Here I would eliminate the idea of mere concentration and confine the thought to the actual composition of the solid material. A thorough study of the composition of a sewage would necessarily include complete determinations of the various organic and inorganic substances present. While such analyses would doubtless be of considerable value in enabling us to understand the reactions involved in purification, yet it is doubtful if our increased knowledge would be at all commensurate with the time and labor involved. By a suitable comparison of the concentration values previously mentioned, however, it may be possible to distinguish between certain types of sewage, such as purely domestic sewage, street washings, and factory and other industrial wastes, and, in the case of a sewage of a mixed and variable type, to describe somewhat roughly its actual composition. Obviously this is a matter requiring careful study in attempting any new purification work.

As a first type for such comparison we may study a number of purely domestic sewages. Such sewages will differ widely in the matter of concentration, but in the relative amounts of nitrogen, carbon, and chlorine they might all be expected to agree within fairly close limits. Variation in these relative numbers would then in any given case denote a variation from the domestic type.

Let us take as an example an actual case. The ratio between the total nitrogen and the chlorine in domestic sewages, as will be shown later, is approximately unity. But at certain times this ratio, in the case of the Boston sewage, may reach as low a figure as one to one hundred, from the backing up of sea water through leaking tide gates. Now if it may be assumed that the normal chlorine value of the sewage in Boston is also equal to the nitrogen, then with the known composition of sea water a simple calculation will show the amount of sea water in the Boston sewage. It is not intended that in ordinary cases the analyst shall attempt in this way to calculate the actual amount of street washings, or other material which has entered the sewage in question, but it is believed that by the use of these composition factors sewages may be classified and compared with each other as to the probable effect upon them of purification treatment.

The third important characteristic of a sewage I have called its condition. By the condition of a sewage I would denote what we variously call its age, freshness, or septicity. But condition as here used is a much more definite property than this, and cannot be expressed as a function of the time alone. Condition is a product of at least three prime factors and of many other minor ones. The three most important are age, temperature, and the number and character of organisms present. Among the other factors may be mentioned the degree of physical disintegration, opportunity for aëration, the presence of germicidal substances, and doubtless many unknown conditions. It will thus become apparent that the mere statement of the age of a sewage, as of a septic sewage, for example, will throw very little light upon its true condition. In attempting to establish condition factors we shall deal not alone with the unvarying constituents, such as the total nitrogen and the total carbon, but with the various forms in which the nitrogen, for example, may occur, and their transformations from one to the other through the activities of the microörganisms or by spontaneous chemical action.

Having now defined the three characteristic properties of a sewage in terms of which we shall attempt to interpret our analytical data, let us examine in some detail our ordinary analytical procedure and see what significance the results have in terms of these properties.

NITROGEN

Nitrogen is determined in four forms, namely, as organic nitrogen, ammoniacal nitrogen, and the nitrogen of nitrous and nitric acids The two latter forms, containing oxygen, are chiefly significant for that reason, and will be discussed under the head of oxygen.

The Organic Nitrogen.—This constituent as determined by the Kjeldahl process is the most valuable of the concentration factors. Nitrogenous organic matter is, *par excellence*, the substance in sewage requiring purification. Its accurate determination is therefore of first importance in a sewage analysis. In addition to its use as a concentration factor the organic nitrogen figure may be usefully combined with other figures to express ratios showing condition and composition.

The Albuminoid Ammonia.—On the question of the value of the albuminoid ammonia figure as an additional aid in fixing the condition of a sewage little need be said. Clark (1904) has published what is perhaps the most thorough study yet made of this question. By averaging a large number of results from similar samples, and from these averages calculating the ratios of the albuminoid ammonia to the organic nitrogen, he obtained somewhat different ratios for the different conditions of the sewage. The individual deviations from these average ratios in any one group are, however, so great as to entirely mask any significance which these ratios may have. The fact that distinctive ratios can be brought out by averaging would seem to indicate that such figures, if accurately determined, might have considerable value, but that the inaccuracies inherent in the Wanklyn process are sufficient to make the individual determination of little value. Obviously the albuminoid ammonia has no value as a concentration factor.

Free Ammonia.—The nitrogen occurring in the form of ammonium hydrate or of ammonium salts is called "nitrogen as free ammonia." The determination, as usually carried out by distillation from alkaline solution, gives results on sewage which are considerably in excess of the true value as thus defined. This excess is due to the breaking down of unstable nitrogenous material. The German procedure of direct nesslerization, after clarification of the sewage, yields results which are much nearer the truth. There is indeed a slight loss due to adsorption of the ammonia by the precipitate, but by proper manipulation this loss may be reduced to a negligible quantity. Since most of our present data ve been obtained by the distillation method, the discussion which fol- s will consider only such results, although the writer is convinced that much more constant and significant ratios could be obtained from the figures if they had been obtained by the direct method.

In a very fresh domestic sewage the ratio of the ammoniacal nitrogen to the organic nitrogen is usually about one to two. This applies only to sewage from a small sewer running swiftly. In the larger intercepting sewers of our cities this ratio will be, as a rule, very close to unity. At the other extreme, an old septic sewage in warm weather may show a ratio as high as seven to one. In calculating the ratio in this case allowance must be made for the fact that sedimentation is taking place. The organic nitrogen value to be used in the ratio is not the actual value found, but should be calculated on the assumption that the total nitrogen — organic plus ammoniacal — has not undergone any diminution during the treatment, an assumption sufficiently exact for this purpose. This total nitrogen value, then, should be taken from the unsedimented sewage. Between these two extremes will be found the ratios for ordinary sewages. The rate of change does not seem to be proportional to the time. The ordinary staling of a sewage is not accompanied by a marked rise in the ratio, while in the later stages of active purification a rapid increase is noted.

This ratio is obviously a factor changing with the age of the sewage. The rate of such a change will be affected by the temperature of the sewage, and will also depend upon the number and nature of organisms present. In a septic tank, for example, the change will take place much more rapidly than during the movement of the sewage through the sewer.

No further experimental proof of the fact of the increase of this ratio with age is needed, for it is a matter of common knowledge. As an illustration of the application of this factor in actual practice, the following analyses of Boston sewage at different seasons are given. This sewage is for the major part less than an hour old. The analyses show the effect upon this condition factor of varying temperature, other things being practically constant.

TABLE I.—SHOWING THE EFFECT OF THE TEMPERATURE UPON THE RATIO OF THE AMMONIACAL TO THE TOTAL NITROGEN

Month.	Average temperature.	Number of determinations.	RATIO OF AMMONIACAL TO ORGANIC NITROGEN.		
			Mean.	Maximum.	Minimum.
July	71	8	1.70	3.35	1.44
September . .	65	8	1.08	1.38	0.79
January	47	10	0.82	1.22	0.47

The value of some such a condition factor in discussing and comparing septic sewages will be readily apparent. The usual method of describing such sewages by age only obviously omits the other important factor — temperature — not to mention possible differences in the number and kinds of bacteria originally present. In describing sewages which have not been subjected to septic treatment, not much has hitherto been attempted. Such terms as fresh and stale sewage have been used without any very sharp definitions. The application of condition factors such as have been described and of which other examples will be given will, it is believed, greatly facilitate our descriptions and even clear our conceptions of these matters.

A New Nitrogen Factor. — The application of the nitrogen analytical data to the question of composition as used in this paper still remains to be worked out. Our data so far do not give us any information as to the ease or difficulty of purifying our nitrogenous matter nor of the stability or non-stability of the nitrogenous matter in an effluent; in other words, we know nothing of the *kind* of nitrogenous matter we are dealing with. In the writer's view these two things are identical, that is, a stable effluent would be difficult, and an unstable one easy of further purification. Furthermore, it is believed that the ability of the nitrogenous matter to hydrolyze is a measure of its non-stability or of its ease of purification. Upon this principle the writer is working out the details of a new nitrogen factor which shall be the desired composition factor. Such a factor is of special value in the analysis of effluents, and, it is hoped, may be fully discussed in the second part of this paper, which will deal more especially with the question of effluents.

CARBON

Our knowledge of the carbon in sewage through our analytical results is meagre indeed. The oxygen-consumed test is a measure of the carbonaceous matter present; unfortunately it is also a measure of the nitrites, ferrous salts, part of the chlorine, and doubtless of many other substances at present unknown to us. Add to this the fact that almost every laboratory has its own method of making the determination, and two things become apparent: first, that the results of the different laboratories are not at all comparable, and, second, that the best of the results have but little real value in the interpretation f an analysis. The arguments which have been used for the accurate determination of the total nitrogen apply with hardly less force to the question of total carbon. The oxygen consumed stands in the same relation to the total carbon as the albuminoid ammonia to the total nitrogen. But the present conditions are much more unsatisfactory in the former case, for the amount of carbon represented is only 2 or 3 per cent. of the total carbon, while the albuminoid ammonia gives one-third or more of the organic nitrogen. What is true of the variable ratio existing between the albuminoid ammonia and the total nitrogen is doubtless equally true as between the oxygen consumed and the total carbon. Hence the oxygen-consumed figures have no value as concentration factors, and, while they may be combined with the total nitrogen figures to form composition ratios, the results are only rough and are not independent of the condition, as composition factors should be. For example, the ratio of the total carbon to the total nitrogen would be an ideal composition factor, since the condition of the sewage would have but slight influence upon it; but the ratio of the oxygen consumed to the total nitrogen will vary with the condition, and hence is not a satisfactory composition factor. It is possible, however, to use this rough factor to distinguish between purely domestic sewage on the one hand and on the other the same sewage mixed with a considerable volume of street washings or of factory wastes from such a process as tanning. Taking the oxygen-consumed figures as determined by the Kubel hot-acid method, with two minutes' boiling we find in a domestic sewage which is reasonably fresh that the oxygen-consumed values are roughly about 50 per cent. greater than the total nitrogen values. Immediately after a heavy shower this value will increase to three or four times the nitrogen figure. The fact must be emphasized, however, that by mere aging of the sewage the same change in this ratio may be brought about.

Since we have but one carbon figure in our analysis, no condition factor based upon carbon alone has been yet developed, although the comparison of values obtained with and without heating seems promising. The change suggested above, while an important correction to the composition factor, is too variable and untrustworthy in its nature to be of any service in denoting condition from the carbon standpoint.

OXYGEN

In any ultimate study of processes of sewage purification, either from the point of view of chemical energetics or of biological metabolism, the oxygen of the organic matter must needs be taken into account. Our present state of knowledge, however, does not warrant any such difficult determination as that of the oxygen of the organic substances, and in the present discussion that oxygen will be left entirely out of consideration. There remain, then, the oxygen which is dissolved in the sewage and that which is present in the form of mineral salts, notably as nitrites and as nitrates. Obviously the oxygen thus present has no relation to the concentration of the sewage, and its incidental and brief occurrence can be of no service in fixing the composition. Oxygen is then of importance only as a condition factor. Its importance in this rôle is so great that its determination becomes one of the most important in our scheme of analysis. In the discussion of the free ammonia-organic nitrogen ratio as a condition factor, it was stated that the increase in this ratio proceeded slowly at first. It is true that even in warm weather sewage may be as old as fifteen hours with but slight indication of the fact from this ratio. When putrefaction once sets in the ammonia ratio is important, but up to that time we must rely entirely upon the oxygen values. Fortunately these are easily determined, and are thoroughly indicative of the condition in the earlier stages. The free dissolved oxygen and the nitrites and nitrates probably enter the sewage with the domestic water, although in cold weather the production of nitrates undoubtedly takes place in the sewage. From that time forward, except under very peculiar circumstances, the tendency is towards the redistribution of this oxygen by the bacteria and their products. The rate of change of the oxygen is therefore a measure of the activity of those bacterial processes which are taking place within the sewage, and which by definition are altering its condition.

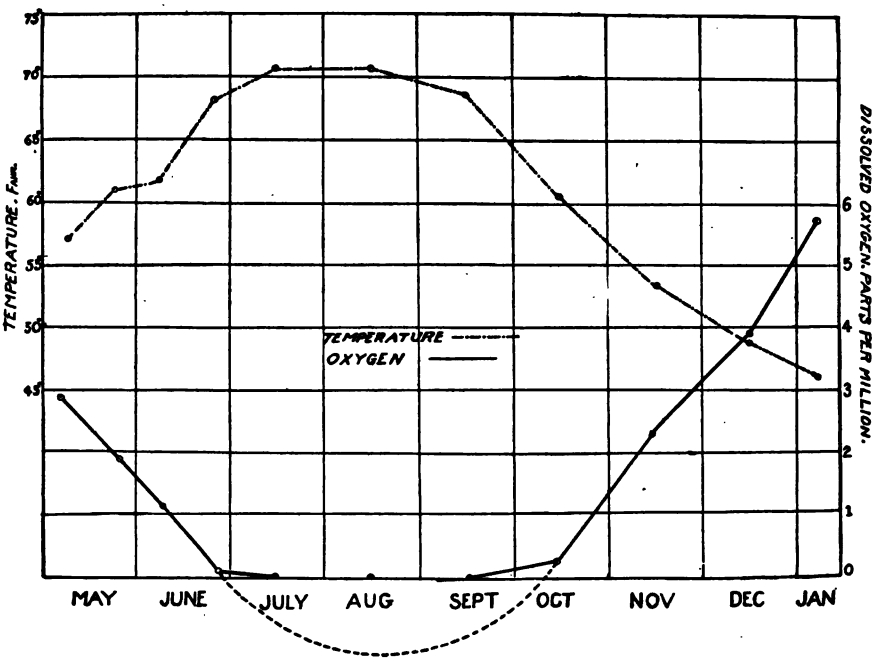
There is some reason to believe that by interaction between the nitrites and certain decomposition products of the sewage, still ultimately due to the bacteria, a certain amount of the nitrites are consumed by direct chemical reaction. Under such extremely anaërobic conditions as are found in the septic tank, other salts, such as the sulphates and phosphates, are likewise reduced. So sensitive is this en test for condition that in the case of the Boston sewage collected at the Sewage Experiment Station, a place at which the majority of the sewage arrives when less than an hour old, the amount of the dissolved oxygen is a seasonal function. It is entirely absent during the three summer months, begins to appear in the early fall, and reaches a maximum value sometime in midwinter, decreasing again as the warmer weather arrives.

In Table II are given these results, together with the temperatures for nine months. The figures given are monthly or semimonthly averages of almost daily determinations. During May and June the changes were so rapid that semimonthly periods were chosen instead of the monthly periods used during the remainder of the year.

TABLE II

Month.	Average temperature, F.	Average amount of dissolved oxygen. Parts per million.
May 1 to 16	57	2.9
May 17 to 31	61	1.9
June 1 to 15	62	1.1
June 16 to 30 . . .	68	0.1
July	71	0.0
August	71	0.0
September	68	0.0
October	61	0.3
November	53	2.2
December	49	3.9
January 1 to 15 . . .	46	5.7

In the accompanying diagram these figures are given in graphical form. From the manner in which the oxygen line approaches the axis, the dotted portion of the line, lying below the axis, is suggested. This would, of course, mean a negative value for the dissolved oxygen. In reality we may have some such a condition as this, although it is not truly a negative dissolved oxygen. After the dissolved oxygen of the sewage is entirely used up, the microörganisms begin to draw upon other substances containing oxygen. Sulphates, phosphates, and ferric



Curves Showing Relation of Temperature to Dissolved Oxygen in Boston Sewage

salts are reduced, giving rise to products which will readily become oxidized again upon exposure to oxygen. If such an extremely anaërobic sewage be mixed with equal portions of water containing, let us say, ten parts per million of dissolved oxygen, and the dissolved oxygen of the mixture determined immediately, the amount found will be small or altogether wanting. It is this ultra-anaërobic condition of a sewage which I have represented by the dotted line, although its existence in this case is purely hypothetical. Its determination by the method indicated is entirely feasible, and the actual condition of a sewage containing no dissolved oxygen can only be expressed in terms of this negative quantity which I would call "*oxygen avidity*."

The order of disappearance of the three forms of oxygen, namely, the free dissolved oxygen and that of the nitrates and the nitrites, seems to vary with the other variable conditions. Nitrates are found in the fresh Boston sewage most commonly in midwinter, and the nitrites generally have their maximum at that time, but there is no such direct seasonal effect noticeable as there is with the free oxygen. In some laboratory experiments made to determine, if possible, the order of disappearance of the three forms, the effect of temperature and of the organisms present was strikingly shown. These experiments were carried out as follows: A sample of fresh sewage was collected directly from the manhole of the sewer. With this three bottles were filled. To each bottle was then added a small amount of paraffin oil to keep the sewage out of contact with the air. Dissolved oxygen samples were then taken from each bottle by means of a siphon. Samples were also taken for nitrates and nitrites. Bottle No. 1 was kept at a temperature of about 10° C., and bottles Nos. 2 and 3 at about 22° C. To bottle No. 3 a small amount of sludge from a septic tank was added in order to seed it with the septic tank organisms. The changes in the amount of dissolved oxygen, nitrates, and nitrites were then studied by determining these substances at intervals. The results of the series are shown in Table III.

TABLE III

EXPERIMENT I. RAW SEWAGE. TEMPERATURE, 10°

Time.	PARTS PER MILLION OF OXYGEN AS		
	Free, dissolved.	Nitrates.	Nitrites.
1/13–10 A.M.	5.8	2.7	3.8
1/13–2 P.M.	5.0	3.0	3.8
1/13–5 P.M.	1.0	10.7	0.8
1/14–10 A.M.	0.0	0.0	0.0
EXPERIMENT II. RAW SEWAGE. TEMPERATURE, 22°			
1/13–10 A.M.	5.7	2.7	3.8
1/13–2 P.M.	2.0	0.0	0.0
1/13–5 P.M.	0.5	0.0	0.0
EXPERIMENT III. RAW SEWAGE SEEDED WITH SEPTIC. TEMPERATURE, 22°			
1/13–10 A.M.	5.5	2.5	3.4
1/13–12 M.	0.0	0.0	1.7
1/13–2 P.M.	0.0	0.0	0.0

Apparently under various conditions of temperature the relative changes in these three substances may be in one or another direction, and these changes are influenced by the bacteria. While it is perfectly feasible to define the several conditions of a sewage in terms of these three oxygen factors, and, if necessary, to determine, as in the experiments cited, the direction of the changes taking place, yet we are not able, with our present knowledge, to apply these condition factors to the practical problems of sewage treatment. That there is a considerable seasonal difference in the results of sewage purification is well known. In ordinary out-of-door work this difference is in favor of the summer season for reasons which are manifest. By eliminating as far as possible the effect of temperature upon the filter itself, which is possible only with small, indoor filters, these seasonal differences are reversed, the fresher winter sewage, with its plentiful supply of oxygen, being much more readily purified. This general observation is about all that we can make at this time. How much of this effect is due to the mere presence of the oxygen in preserving the activity of the filter, how much to the preponderance of bacterial nitrification over bacterial reduction (as shown in Experiment I), and how much to the absence of putrefactive changes which are themselves induced largely by the lack of oxygen, are questions to be answered by future investigations, and they are questions which must be fairly met and answered before we may claim to have a thorough knowledge of the purification processes with which we are dealing.

One word may be said in favor of the practical use of the condition factors here suggested. Results obtained empirically on any one sewage will be made available for general use only after we have discovered what are the important characteristics of sewage in relation to its treatment. Concentration and, to a large extent, composition characteristics are directly comparable. If these condition factors are found to be essential ones in determining the results of sewage treatment, then we may reasonably hope in the near future to be able to make use of the large amount of empirical data which today has little value except in reference to the sewage on which it was obtained.

CHLORINE

It would seem from wholly *à priori* reasoning that the relation of the chlorine to the total nitrogen in sewages from various localities would a fairly constant quantity, these two elements being both of fundamental character in food. Such, indeed, is the case in the majority of instances, although an occasional striking exception seems to lessen the value of the ratio in fixing the composition of a sewage. Unfortunately the data available for determining this ratio with exactness are very meagre. Clark (1904) gives the results of total nitrogen determinations on the sewages of sixteen cities and towns of Massachusetts. Five or six determinations were made on each sewage; the albuminoid ammonia determinations were made at the same time. From this series of results the writer has calculated the average ratio between the albuminoid ammonia and the organic nitrogen for each locality. In another place in the same report are given yearly averages of monthly analyses of these same sewages, but without organic nitrogen determinations. Applying the ratio previously found to the albuminoid ammonia figures given in these averages, it has been possible to estimate with fair accuracy the amount of organic nitrogen, and from this to establish the desired chlorine-nitrogen ratio. Table IV contains the results obtained in this way. Some results obtained by Fuller (1894) from four of these localities and one other, as well as the results from three English cities obtained by Rideal (1904), are also given.

The sewages from these cities and towns show, with a few exceptions, a fairly constant chlorine-nitrogen ratio of from one to one and a half. Three of the sewages are strikingly peculiar — Concord, Lawrence, and Natick. In Concord a large amount of ground water finds its way into the sewers, as is indicated by the extreme dilution of the nitrogenous material. There can be little doubt that a large part of this water is purified sewage with a high chlorine value. In Lawrence the very abnormal chlorine value may be due to mill liquor. Both Natick and Leicester have dilute sewages whose high chlorine ratios may be due to chlorine in the diluting ground water. The fact that a fairly constant ratio can be obtained in the case of most localities makes it seem very probable that the exceptions represent real variations from the normal domestic type.

TABLE IV.—SHOWING THE RATIO OF THE CHLORINE TO THE TOTAL NITROGEN IN SEWAGES FROM VARIOUS SOURCES

(Parts per million)

Place.	Nitrogen as			Chlorine.	Cl ÷ N
	Free ammonia.	Total organic (calc.).	Total.		
Andover	39.7	16.8	56.5	70.0	1.2
Clinton	33.3	23.7	57.0	59.5	1.0
Concord	5.7	4.2	9.9	26.6	2.7
Framingham	26.1	16.3	42.4	69.9	1.6
Gardner (old)	20.2	14.8	35.0	33.8	1.0
Gardner (new)	27.3	19.8	47.1	43.8	0.9
Hopedale	18.3	8.5	26.8	22.3	0.8
Lawrence	18.1	23.4	41.5	120.1	2.9
Leicester	22.0	8.3	30.3	54.7	1.8
Marlborough	25.9	14.8	40.7	59.0	1.4
Natick	12.2	7.9	20.1	59.5	2.9
Pittsfield	12.0	20.4	32.4	25.7	0.8
Southbridge	16.1	8.9	25.0	29.0	1.2
Spencer	14.9	11.4	26.3	39.9	1.5
Stockbridge	9.8	3.3	13.1	12.8	1.0
Westborough	13.8	11.1	24.9	23.7	1.0
Framingham	22.0	14.9	36.9	27.0	0.7
Gardner	8.8	9.6	18.4	29.0	1.6
Lawrence	10.8	14.5	25.3	37.5	1.5
Marlborough	27.1	20.4	47.5	45.0	0.9
Worcester Hospital	6.1	32.0	38.1	32.5	0.9
Exeter, England	. .	. .	63.7	75.0	1.2
Sutton, England	. .	. .	88.1	89.9	1.0
London, England	. .	. .	70.6	104.0	1.5

FATS AND FATTY BODIES

The determination of the fats and soaps in sewage is one whose importance is generally overlooked. These bodies are undoubtedly responsible for much of the clogging properties of a sewage which are noticed particularly in sand filtration. The fats, being non-miscible with water, are the less readily decomposed, a feature which is augmented by the very stable nature of the bodies themselves. Clark (1904) gives as the average yearly amount of these bodies, fats and soaps combined, in the Lawrence sewage about six parts per hundred thousand, or 20 per cent. of the total combustible solids. In the treatment of the sewage of large private country residences great difficulty is found in properly dealing with the fats, which in this case amount to a very much larger percentage of the total solids. In one such case which has recently come under the writer's study the sewage contained 2,100 parts per million of volatile solids, of which 1,400 parts per million, or 66 per cent., were fats. In our interpretation the fats have a value as concentration factors only. Their determination is of considerable importance for the sake of comparisons, and should be made regularly in any systematic study. An occasional determination of the separate substances, free fats, and soluble and insoluble soaps, would also add to our knowledge of the character of the sewage. This separation is easily made by the use of suitable solvents.

IRON, SULPHUR, AND PHOSPHORUS

The determination of these elements is not, as a rule, made in routine work. It would be extremely useful, however, to establish the normal amounts of these elements present in domestic sewages from various localities. Such data would be of value in calculating the amount of added industrial waste or other liquor which contained these elements. During the past year the writer has collected during each week an average sample of Boston sewage composed of equal portions of each daily sample. On this sample the iron and sulphates have been determined. The sulphates in this case are influenced by the presence of sea water and are, therefore, of no significance here. The iron-nitrogen ratio is found to be 0.2 for the yearly average. Variations in this ratio are slight.

TURBIDITY, SEDIMENT, AND SOLIDS. LOSS ON IGNITION

The turbidity, if determined by a properly standardized method, is a rough measure of the suspended solid matter. The sediment is the amount of this matter which has settled out after a given period. The total solids are usually determined on the filtered as well as the unfiltered sample. The difference between these two determinations gives the amount of solid matter in suspension, that is, the turbidity. Probably the most accurate optical method of estimating turbidity is by some such instrument as the Jackson turbidimeter.[1] This instrument is calibrated against finely divided silica, and its readings on turbid waters are in close agreement with the actual gravimetric values found for the solids in suspension. It is unfortunately true that an optical instrument of this nature gives correct values only when the suspended matter to be determined is of the same size as that matter against which the instrument was calibrated. In reading sewage turbidities in terms of silica there is a greater and greater variation between the turbidities and the actual solids in suspension as the size of the suspended particles increases. Clark (1904, *a*) has recently proposed as a standard for sewage turbidities, and especially for the fairly coarse suspended matter in certain filter effluents, a suspension containing a known amount of this same coarse and at the same time fairly stable material. From this standards may be made up containing varying amounts of the suspended solids. By using such a material to recalibrate the Jackson turbidimeter, one should be able to read the solids in suspension in a sample of sewage with a very fair degree of accuracy. If the suspended solids are determined in this way there seems to be little need for the total solids determination. Its results are at best open to suspicion, owing to the difficulty of completely drying a sample without loss of organic matter. This is especially true in the presence of deliquescent salts.

The sediment may be determined by a second reading of the turbidity after the sample has stood for a standard length of time.

The loss on ignition shows in a rough way the amount of the total solids which are volatile at a low red heat. It therefore includes the organic matter, with the exception of some of the carbon which may remain behind as alkaline carbonate. It also includes all such volatile substances as ammonium carbonate and chloride, and to a slight extent other mineral salts. The determination has never been regarded as one of much value.

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[1] TECHNOLOGY QUARTERLY, 1901, XIV, pp. 285–294.

ALKALINITY

Domestic sewage is normally slightly alkaline. The alkalinity of a sewage has little significance in the interpretation unless it has an abnormal value. Such a characteristic might indicate the presence of industrial wastes which would otherwise have escaped notice.

BACTERIA

The determination of the number of bacteria present in the sewage gives us in general little if any additional knowledge as to its characteristics. In certain special cases their total absence or presence in comparatively small numbers might direct the attention of the analyst to the presence of germicidal bodies in the sewage which would have otherwise escaped detection. In the discussion of the question of effluents the determination of the number and kinds of bacteria will be shown to have considerable significance.

UNFILTERED AND FILTERED SAMPLES

It is the usual custom in this country to make the principal determinations both upon the unfiltered sample and upon a sample which has been passed through filter paper. The differences noted are assumed to represent the amount of the substance in question which has been removed by filtration, and hence roughly the amount in suspension. In the determination of the total nitrogen or total carbon, such an assumption is legitimate. In using such comparative processes as the albuminoid ammonia and the oxygen-consumed processes, however, an error of considerable magnitude is thereby introduced. For example, the writer found in an extended comparison of the albuminoid ammonia with the organic nitrogen, that as an average of a number of determinations 40 per cent. of the dissolved nitrogen and only 25 per cent. of the suspended nitrogen were recovered as albuminoid ammonia. In such a case the albuminoid ammonia might show equal amounts of nitrogen dissolved and suspended, when actually nearly two-thirds of the total would be in suspension.

In Germany and among certain English analysts samples are always filtered through paper before analysis. Such analyses are then published as analyses of the sewage. In defense of this practice it is said that an analysis of the sewage itself and not of the suspended solids is what is desired. Further comment is unnecessary except to state that such analyses are in no way comparable with our own.

CONCLUSION

In conclusion it may be well to bring together the various important analytical figures and factors which have been discussed in the preceding pages.

For concentration factors we should have determinations of the total nitrogen, total carbon, chlorine, and fats and soaps. Of minor importance, but useful in a systematic study for comparison, are the determinations of the sulphates, phosphates, and iron.

For composition factors the ratio of chlorine to nitrogen is perhaps under the present conditions of our analytical methods the best that we have. With the determination of the total carbon, the carbon-nitrogen ratio ought to prove of even greater value. The ratio of oxygen consumed to total nitrogen is only rough at best and is not independent of condition. It will, however, indicate any considerable change in the character of a given sewage, such a change as would be caused, for example, by a heavy summer shower.

For condition factors we have at present two independent sets of numbers. The oxygen values as found in the dissolved oxygen, nitrates, and nitrites serve as an admirable index of the condition of a sewage before putrefaction becomes active. During the later stages the free ammonia-organic nitrogen ratio is of great significance. The ratio of carbon oxidized by permanganate to total carbon may be found to have some value in determining condition. As a first prerequisite, however, a method must be developed for the oxygen consumed determination which can lay some claim to accuracy and constancy. In the accompanying sewage analysis there are given in ordinary type the analytical data which the writer believes will be found essential to a satisfactory interpretation of the analysis. The determinations in italics are not regarded as essential, but are of value in a systematic study of various sewages. New determinations will undoubtedly be added, such as, for instance, one which will show the tendency of the nitrogenous matter to hydrolyze (putrefy); possibly some new ratios will be found to denote condition, but in the main the analysis here given is an example of what ought to be done in sewage analysis. No argument based upon the time consumed in making such an analysis should have weight against the adoption of this procedure. The tendency should be towards average samples taken from the whole day's run of sewage or the whole discharge of an effluent. A thorough knowledge of the action of various germicidal bodies in preserving such samples is desirable. Certain determinations will doubtless have to be made immediately, but the majority of the determinations here recommended can be made on an average sample of one whole week if necessary. Fewer but more representative samples examined thoroughly will take no more time than the rough analysis of many samples.

The writer would emphasize the statement already made that the object of these proposed factors is not to enable the analyst to say that any given sewage is of a certain age or of a certain composition. Such information might be more readily and accurately gathered from a survey of the sewerage system, and in fact no such concrete reference can be made from the analysis. It is known, however, that a study of our filtration results, and especially those obtained at our experimental plants, leads us at present only to empirical data which are correlated but slightly with one another or with the results from other plants. It seems more than probable that such a condition is due to lack of proper interpretation of our analyses, and that if we can truly interpret these analyses in terms of essential characteristics from the point of view of purification, and study our purification results on the basis of this interpretation, then we shall find that these results are correlated with the analyses and with one another, and that it may be more possible than heretofore to predict the probable effect of treating a given sewage by a given system of purification.

In the present paper we have considered only the subject of raw or untreated sewages and of septic sewages. The analysis of the effluent of a sewage filter is made for the distinct purpose of estimating the efficiency of the process of purification, and the interpretation of such an analysis requires a treatment quite distinct from that given here to sewage analyses. In a future paper the writer hopes to take up the discussion of this other important phase of the interpretation of sewage analysis.

TABLE V. — SPECIMEN SEWAGE ANALYSIS

	PARTS PER MILLION.		
	Total.	**Dissolved.**	**Suspended.**
NITROGEN:			
Total	55.6	40.6	15.0
Organic	30.0	15.0	15.0
As NH_3	25.0	. .	. .
As N_2O_3	0.1	. .	. .
As N_2O_5	0.5	. .	. .
CARBON:			
Total	280.0	120.0	160.0
By $KMnO_4$	14.0	8.0	6.0
As CO_2	5.0	. .	. .
CHLORINE	60.0	. .	. .
OXYGEN:			
Dissolved	10.0	. .	. .
FATTY ACIDS:			
Total	61.0	30.0	31.0
Saponified	35.0	30.0	5.0
Unsaponified	26.0	. .	26.0
Sulphur	7.0	. .	. .
Phosphorus	1.0	. .	. .
Iron	12.0	. .	. .
Alkalinity	212.0	. .	. .
TURBIDITY:			
Total	320.0	. .	. .
On standing	260.0	. .	. .
Sediment (diff.)	60.0	. .	. .

RATIOS:	
Carbon-nitrogen	5.1
Chlorine-nitrogen	1.1
Ammoniacal-organic nitrogen	0.83
Carbon by $KMnO_4$*-total carbon*	0.05

LITERATURE

Clark, H. W. 1904. Report of the Massachusetts State Board of Health for 1903, pp. 229 *et seq.*, 312 *et seq.*

Clark, H. W. 1904, *a.* Jour. Ass'n Eng. Soc., 1904, XXXIII, p. 356.

Fuller, G. W. 1895. Report of the Massachusetts State Board of Health for 1894, p. 471.

Rideal, S. 1904. Interim Report of the Royal Commission on Sewage Disposal, 902, II, p. 256.

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

II

THE INTERPRETATION OF AN ANALYSIS OF THE EFFLUENT FROM A SEWAGE FILTER

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(Received April 3, 1905)

IN a previous paper the writer (1905) has described certain characteristics of a sewage, in terms of which the analytical figures may be interpreted, in order that sewages may be described and classified with reference to purification. The subject of sewage filter effluents, requiring, as it does, a distinctly different manner of treatment, was not considered at that time. The proper interpretation of the analyses of such effluents, however, is equally important in experimental work, and is the essential point in the work of the practical sewage filter. In the present paper it is the intention to discuss this phase of the sewage purification problem. Septic sewage was considered in the previous paper as a sewage to be purified. It must also be considered here, but as a partially purified effluent.

The subject of the quality of the effluents derived from a sewage filter has been considered from two totally different points of view, which have led frequently to conflicting opinions as to the results obtained. One view is based upon the actual work of the filter expressed in percentage efficiency, and necessarily takes into account the nature of the raw sewage. The other is based upon the quality of the effluent as shown by the analysis.

The former is, as a rule, the point of view of the investigator who is comparing the work of several types of filters upon the same sewage, and who finds in the percentage efficiencies of the several filters a convenient basis for such comparisons. The latter is the broader view of the sanitarian and of the public health official, whose duty it is to inquire, not what is the percentage removal of organic matter, but what will be the probable effect upon the health and comfort of the communities below of the discharge of this effluent into a stream. Both viewpoints must be taken, each supplementing the other.

The expression, "percentage removal," sometimes called the efficiency of the filter, is of very little value in the comparison of systems which are not receiving the same sewage, for it is much easier to get a high efficiency, calculated in this way, on a strong sewage than on one which is weaker. The figure in any case is of real value only when it is based upon determinations which are themselves total and not partial determinations. For example, it is obvious that the total organic nitrogen or total organic carbon of the raw sewage and of the effluent may be directly compared; but the comparison of such partial values as those of the albuminoid ammonia or of the oxygen consumed will give only misleading results. Whatever value such determinations may have in the comparison of like substances is entirely lost when the substances are unlike. The removal of bacteria may properly be expressed in the form of efficiency, but in the case of very good effluents this form of expressing results fails in another respect, in that a very short range of numerical efficiencies covers a wide range of actual conditions. For example, it might not readily be noted that in a given filter a change from 99.9 per cent. to 99.8 per cent. in the bacterial efficiency would mean a doubling of the bacteria in the effluent, while smaller but significant changes in the effluent would not appear in the efficiency number. On the whole it would seem that a better interpretation of the analysis of an effluent can be made than this customary comparison with the raw sewage. A direct comparison of effluents derived from the same sewage will serve the purposes of the investigator fully as well as a comparison of the efficiencies, while the quality of the effluent is the final and practical criterion upon which the work of the filter must be judged.

HISTORICAL. STANDARDS OF PURITY

In an act of the English Parliament of 1861, entitled "Local Government Act Amendment Act" (Great Britain, 1861), a provision prohibits the construction of new sewer outfalls which shall discharge any "sewage or filthy water into any natural water course or stream until such sewage or filthy or refuse water be freed from all excrementitious or other foul or noxious matter such as would affect or deteriorate the purity and quality of the water in such stream or water course." This act is of interest in that it is the first law, in England at least, requiring treatment of sewage. At that time no standards were available, and it would be of interest to learn just how it was determined when all such "excrementitious and foul matter" had been removed.

As early as 1872 (Great Britain, 1872), the first Rivers' Pollution Commission of England recommended the following standards of purity for effluents. A nonpolluting liquid shall not contain in 100,000 parts over three parts of mineral matter or over one part of organic matter in suspension; nor in solution shall it contain over two parts of organic carbon or 0.3 part organic nitrogen. This standard would have prevented the discharge of any but the most perfectly purified effluents. The recommendations were never embodied in the law, and never since that time have the established standards been so exacting. The following standards, all expressed in parts per 100,000, have almost legal force in the various districts of England (Rideal, 1902) — Thames Conservancy: organic carbon 3.0, organic nitrogen 1.1; Derbyshire County Council: albuminoid ammonia 0.1, oxygen absorbed 1.0; Ribble Board: albuminoid ammonia 0.1, oxygen absorbed 2.0; Mersey and Irwell: albuminoid ammonia .14, oxygen absorbed 1.4.

It will be seen at once that mere dilution of the effluent will bring it within the limits of any such standards, which are based upon actual amounts of organic matter present. It is even claimed by the sanitary inspectors that certain manufacturers use this method as their sole means of bringing their waste liquors down to the required standard.

Since the introduction of the more recent biological processes our ideas of purity of effluents have been gradually changing. In many of these processes, but most notably in the case of the continuous, or trickling, filter, a large amount of organic matter is passed through the filter, which upon examination generally proves to be of a peaty or humus nature and incapable of further putrefactive change. Aside from the possibility of such material creating a nuisance by forming deposits behind milldams or in the lower reaches of the stream, it appears to be entirely harmless and nonoffensive. Chemical analysis fails to distinguish between the ordinary putrescible matter of sewage and this non-putrescible material which results from the treatment of the sewage in the manner indicated. This has led to the introduction of putrescibility, or incubation, tests which are now so commonly used.

lepend in general upon the storage of the effluent in a bottle ner temperature and out of contact with the air for a period of days. Certain tests are then made upon this incubated sample mine if it has undergone putrefaction. The determination of gen consumed before and after incubation is the one most fre- employed. Many chemists determine the loss of dissolved and of nitrates either in the original effluent or after mixing certain quantities of aërated water or nitrate solution.

ntion has also been called to the value of the nitrates in an Gayon and Dupetite (1886) have shown that denitrification ct combustion of organic carbon at the expense of the oxygen nitrates. Experiments of Adney and of Letts tend to confirm v. It is also brought out by these investigators that the free d oxygen likewise takes part in the reactions, carbon dioxide volved in amount corresponding to the free oxygen used up. istead of adhering to the older view that all organic matter is and must be kept below a certain maximum standard value, e recent practice is to balance the available oxygen against the matter, and, if the former be found in excess, to consider the satisfactory. The question remaining to be settled, and on here are many views, is just how much of the oxygen is and how much of the organic matter requires oxidation.

se and other considerations have led to the construction by 1902) of a formula for the discharge of effluents into a stream, e proposes as a practical standard of purity for effluents. This is:—

$$C = \frac{XO}{(M-N)S},$$

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low of the stream in hectoliters per minute.

rams of free oxygen in 1 hectoliter

ectoliters of effluent discharged per minute.

rams of oxygen required to consume the organic matter in hectoliter of effluent as determined by the permanganate test, oiling for four hours and deducting for the nitrites.

rams of available oxygen as free oxygen, nitrate, and nitrite O_2 for N_2O_5, O_2 for N_2O_3).

atio between the amount of oxygen in the stream and the nount of this required to oxidize the organic matter.

This formula serves to distinguish three possible cases. If *C* be negative, the effluent not only will not putrefy by itself, but by virtue of its excess of available oxygen will tend to improve the condition of the stream, if the latter be already polluted. If *C* be greater than unity, the effluent will draw upon the oxidizing power of the stream, diminishing the power of the latter to deal successfully with further pollution; but in this case the stream will not itself become foul from this effluent. If *C* be positive, but less than unity, the stream will be overburdened by the addition of the effluent, and will become foul.

In England, where the subject of streams pollution has received careful study, the opinions of the experts on this question of standards vary greatly. The late Sir Edward Frankland (1902), in his testimony before the Royal Sewage Commission, restated the proposition advanced by him in 1874, that "there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation." Frankland also expressed distrust of the incubation test, believing it to be unreliable. On the other hand, the position taken by Rideal, that all free oxygen, as well as the oxygen of the nitrates and nitrites, is available to complete the oxidation of the remaining organic matter, was supported by much of the testimony. The same views are embodied in a test proposed by Adney (1902), who would incubate a sample of the effluent after diluting with river water in the proportion in which the two are mixed in the river. Then if no putrefaction occurs the effluent is satisfactory.

This test represents the extreme view of that school of sanitarians who hold that, if a partially purified effluent can be supplied with sufficient available oxygen for the complete oxidation of the remaining organic matter, it may with safety be discharged into the stream, and the purification will be completely carried out within the stream. In justice to this view, it should be stated that what is here attempted is apparently not the protection of the streams from pollution by disease germs so much as the prevention of an apparent nuisance in, or fouling of, the stream. The evident intention is to keep the stream in such a condition that it may be rendered fit for domestic use by further purification of the water.

With our present knowledge, at least, this would seem to be the wiser provision. We know little, unfortunately, of the viability of disease organisms in sewage and of the effect of purification treatment upon them. While the ideal condition, and the one toward which sanitarians should ever be working, is the perfect purification of sewage from all pathogenic bacteria before discharge, it may nevertheless be better economy, with our present information, so to purify our sewage as to prevent it from seriously fouling the streams and to thoroughly purify all waters taken from them for domestic use. With the idea, therefore, of interpreting our analyses of effluents in accordance with this view, let us examine our analytical procedure in connection with the purification processes to see what significance each of the substances determined has upon the interpretation of the analysis of an effluent. At the same time the fact must not be overlooked that practically perfect purification from the bacterial point of view is entirely feasible, and in many cases desirable. The question of the interpretation of slow-sand-filter effluents will, therefore, naturally be included in the present discussion.

NITROGEN

According as the conditions of the purification process are aërobic or anaërobic, the nitrogen of the organic molecule may follow one or the other of two very different courses. In the slow sand filter and also in the percolating, or trickling, filter, in both of which types there is a plentiful supply of oxygen, the course of all the nitrogen seems to be from organic molecule to ammonia, and thence to nitrites and nitrates. In a very good sand filter as much as 99 per cent. of the organic nitrogen may be thus accounted for. On the other hand, Farrell and the writer (1905) have recently shown that in the contact system of purification, while as much as 25 per cent. of the total nitrogen may follow this course, a large part of the remainder is converted, under the anaërobic conditions of the reduction phase, into the amine form, and that these amines in turn react with the nitrites previously formed. This reaction causes a liberation of a large percentage of the total nitrogen in the form of the free gas. As much as 50 per cent. of the total may thus disappear. In the septic tank also nitrogen is liberated, but in this case the liberation is brought about by the direct action of the microörganisms upon the organic molecule. Kinnicutt and Eddy (1901) have published the results of what is probably the most careful study ever made of the amount and composition of the gas given off in the septic tank. As a result of their work upon the Worcester sewage, extending over a period of a little over two years, they found for the first fifteen months the average amount of gas evolved was 2.3 gallons per 100 gallons of sewage, and that of this gas 32 per cent. was nitrogen. A simple calculation shows this amount to represent 9.8 parts per million of sewage. The total nitrogen value for the raw sewage, as given by Eddy (1901), is 42.5 parts per million, so that 23 per cent. of the total is evolved in the tank as nitrogen gas. During the following year the average results similarly calculated are 8.5 parts per million evolved, or 17 per cent. of the total nitrogen of the sewage. The latter figure itself is not given for that year, and is here calculated approximately by the formula proposed by Fuller (1903), which is,

$$\text{Total organic nitrogen} = \frac{12 \times (\text{albuminoid nitrogen})^2}{\text{ammoniacal nitrogen}}.$$

Similar calculation made upon some results obtained by Clark (1900) on the Lawrence sewage shows an evolution of nine parts per million of nitrogen in a sewage which contains approximately forty parts per million of nitrogen as calculated by the above formula. The nitrogen evolved in this case is therefore about 22 per cent. of the total.

In Manchester, England, Fowler (1901) has made some analyses and measurements of the gas in a septic tank. His results, calculated into parts of nitrogen per million, give 12.5 parts. Averages of the raw sewage are not given, but, judging from the septic tank effluent, the sewage is of about the same strength as that of Lawrence.

Knowledge of the actual amount of nitrogen escaping from the septic tank or from a contact filter is obviously of great importance, and the value of total nitrogen determination as an index of the work of these processes is evident.

The Free Ammonia.—The free ammonia being a transition stage in the purification process is not of much significance in those rapid processes of treatment where a large amount of ammonia is produced in a short time. While it is strictly an inorganic substance, and in every way harmless, yet the fact must not be overlooked that it is not a stable compound when discharged into a stream. All the free ammonia must be oxidized at the expense of the free oxygen of the stream, and its effect in thus reducing the power of the stream to further purify organic matter must be allowed for. This fact is not considered in Rideal's formula previously given. In very pure effluents, such as those from sand filters, the free ammonia, being extremely low, is a valuable index of the work of the filter. In such cases it may be said that it runs very nearly parallel with the organic nitrogen as well as with the bacteria.

Nitrites. — The nitrites are likewise transition substances, and are extremely unstable. In filters of the oxidizing type, nitrites are a valuable indication of the condition of the filter. When such a filter is running at its best, the nitrites will, as a rule, be low. A marked increase in the nitrite value is then an indication that something has gone wrong with the filter. Considered with reference to the stream, they are of value in that they possess available oxygen, although as a rule the amount of nitrites present is too small to be of any value in this respect. Their great importance in the reactions of the contact filter has already been alluded to.

Nitrates. — Nitrates are the final product of the oxidation of the organic nitrogen. Their appearance in sand and trickling filters is, therefore, of great significance, in that they indicate the actual amount of work done by the filter. Their relation to the quality of the effluent is also important. They carry the largest amount of the available oxygen of the effluent, and it is now believed by most authorities that they may be entirely consumed in the process of secondary oxidation, which takes place in the stream after the discharge of the effluent. Any arbitrary standard for purity for effluents from such filters should therefore contain, in addition to a maximum allowable amount of organic matter, a minimum amount of nitrates. In such a case mere dilution of an effluent could never bring it to the desired condition, while with high nitrates an effluent will not generally become foul or offensive by secondary putrefaction.

Authorities are not yet in agreement as to the significance of nitrates in the contact filter effluent. This point has been discussed in detail in the paper on the contact filter previously referred to (Phelps and Farrell, 1905), and will not be taken up here. The writer's opinion is that since nitrates are used up in the work of the filter, their appearance in the effluent merely indicates that an excess has been formed, and that if necessary the filter may be worked harder. Perfectly stable effluents may be obtained practically free from nitrates.

CARBON

The organic carbon is determined only partially by the oxygen-consumed test. While this test has a certain value in the comparison of effluents from similar filters, and especially as a quick method for controlling a filter, it has no scientific basis whatever, and the relation of its results to the total carbon is, so far as the writer is aware, unknown. In a few experiments made by Mr. Roger L. Rice under the writer's direction it was found that the percentage of the total carbon of various organic substances given by this test varied all the way from a few per cent. in the case of cane sugar to 100 per cent. in the case of such bodies as ammonium oxalate. The futility, therefore, of attempting to calculate the efficiency of a process upon the basis of the test is apparent. It has been claimed that with a four hours' boiling this process determines the total carbon, and Rideal has worked out his formula for purity of effluents on this assumption. The subject of the determination of the total carbon by a method which shall be fairly accurate and at the same time sufficiently rapid and easy for routine sewage work is one which should receive the attention of sewage chemists. The question whether or not the oxygen consumed as now determined, or as it may be determined by some modification of the present process, bears any significant relation to the total can then be considered, and it is very possible that a relation may be obtained which shall show the ease with which the organic carbon can be oxidized. This latter point is, of course, an important one in the consideration of the stability of the effluent. The oxygen-consumed determination is of undoubted value in the putrescibility tests, which will be considered later.

OXYGEN

Free dissolved oxygen in the effluent represents a reserve oxidizing power by which the effluent can further purify itself. Its presence also indicates that there has been a sufficient supply of this necessary element during the process of purification. The effluents of oxidizing filters, sand and trickling filters, should always contain free oxygen. If all the oxygen is used up, then the process is not being properly worked. In the contact-filter effluent the free oxygen has another significance. The supply of oxygen being necessarily somewhat limited in this type of filter, it will become most completely exhausted in that filter which is doing the most work. We find that this is actually the case at the Sewage Experiment Station treating Boston sewage. Our best contact-filter effluents are, as a rule, free from dissolved oxygen, while others, although less well purified, contain oxygen. This effluent, which is free from dissolved oxygen, might be looked upon with suspicion but that it contains high nitrates, and has thus an available reserve of oxygen in another form. There may be some doubt as to which of these two effluents is really the better. They would doubtless both give similar values for *C* in Rideal's formula. Incubation tests are strongly in favor of the one containing nitrates.

PUTRESCIBILITY TESTS

By putrescibility we denote that property of the organic matter in a sewage or effluent which causes it, under certain conditions, to undergo putrefactive change. Thus gelatin is a putrescible substance, while peat is a good example of a non-putrescible, or stable, substance. For the purposes of sewage work, the organic matter dealt with may be roughly grouped into these two classes, for it is now pretty generally conceded that, in addition to the readily putrescible organic matter which characterizes sewages, there is also found in effluents organic matter of the other class, that is, stable organic matter. Bodies belonging to this latter group may already exist to some extent in the raw sewage, and they are the characteristic end-products of the rapid oxidation of the sewage in a trickling filter. They are not produced appreciably in the anaërobic decompositions of the septic tank, and would, therefore, appear to be the result of the direct oxidation of the organic molecule rather than of its hydrolitic cleavage. This view may be illustrated by the two following hypothetical reactions:—

$$\text{Oxidation, } 2R{-}N{=}R' + 3O_2 = R{-}O{-}R + 2R'{=}O + N_2O_3.$$
$$\text{Hydrolysis, } R{-}N{=}R' + H_2O = R{-}OH + R'{=}NH.$$

In other words, hydrolytic cleavage produces amines and complex, perhaps unsaturated, hydroxyl bodies, while oxidation produces ultimately oxides of nitrogen and organic molecules which do not readily take up more oxygen.

Water analysts feel strongly the need of distinguishing between these two classes of bodies in potable waters represented by animal pollution on the one hand and by vegetable extractive matter on the other. Many attempts have been made to devise an analytical process for this purpose. Woodman (1898) has proposed a method which is worthy of wider adoption. He would determine the oxygen consumed by the regular method from permanganate and again from chromic acid.

The ratio between these two values is a characteristic one for each of the two classes of material. The water analyst, however, has other determinations upon which he can rely to aid in his interpretation. The chlorine, nitrites, and nitrates each have their own significance, and help to explain the origin of the organic matter.

In sewage analysis nothing in the ordinary procedure serves to give any clew to this question of the character of the organic matter. Therefore about 1895 Scudder (1902) devised as a simple method of studying this point the test which has since come to be known as the incubator test. In its earliest form this test consisted in completely filling a bottle with the effluent and keeping it stoppered at a warm summer temperature for a few days. If it was then free from odor and from all signs of decomposition, it was considered nonputrescible. Later Scudder placed this test upon a more scientific basis by determining the oxygen consumed from permanganate in the cold in three minutes, the dissolved oxygen and the nitrates both before and after incubation. A putrescible effluent as defined by him will have lost part of or all its dissolved oxygen and nitrates, and will absorb an increased amount of oxygen from permanganate.

The writer's experience with the incubation test upon many kinds of effluents leads him to believe that the observed changes in the amount of available oxygen and in the oxygen-consuming power of the effluent during incubation serve to indicate three different conditions of the effluents, rather than two only, and that the interpretation of the test from this point of view makes it the most valuable one in our analytical procedure. The following classification of the results of the test will make this view plain: —

1. There is no loss of available oxygen during the incubation.
2. There is loss of available oxygen.

a. The loss is only partial. The oxygen-consumed value is unchanged or diminished. The effluent remains clear without the production of disagreeable odor.

b. The loss is total. The oxygen-consumed value is increased. Putrefaction has occurred with the production of disagreeable odors, and usually of a dark sediment.

In case 1 the organic matter is stable, or nonputrescible, in the true sense of the word. Such an effluent would pass the incubation test in its strictest form as recommended by Scudder. Case 2 *a* represents an effluent whose organic matter is not completely stable. The putrescibility of this organic matter is not determined by the test, since anaërobic conditions have not been established. This material might, under such conditions, have become putrescent, but the supply of available oxygen in the effluent is more than sufficient to render it stable and nonputrescent. Although the available oxygen is diminished and the effluent would not, therefore, pass the test as used by Scudder, it is nevertheless apparent that it contains within itself the power to complete its own purification, and thus could not under any conditions become foul. Case *2 b* is an example of an effluent which cannot complete its own purification, and would draw upon the purifying power of the stream. Its effect upon the stream, therefore, would depend upon other considerations, namely, relative volumes of the stream and of the effluent, character of the stream as regards previous pollution and available oxygen, etc. For the further study of such an effluent Adney's proposed test will be of service. This test consists in mixing the effluent with the water of the stream in the proportion of the relative volumes of their flows, and then incubating. Whether or not the stream will be able to complete the oxidation of the effluent will be shown by this test. But one must not overlook the fact that one is working here on a very narrow margin of safety, and careful consideration must be given to the possible seasonal variations in the quality and flow of the stream. In general, effluents of this character ought not to be discharged. They constitute pollution even when no immediate nuisance is produced. Their effect upon the river is cumulative, and in the case of a stream receiving such effluents from a number of communities the first discharge might be of untreated sewage, while the communities lower down would be obliged to produce a very pure effluent in order to prevent fouling of the stream.

In carrying out the determinations connected with the incubation test certain special methods of procedure are necessary. For example, it is found that the determination of the oxygen consumed by the shorter English method — three minutes in the cold — rather than by the hot method emphasizes greatly the changes occurring during the incubation. The writer has also found it quite necessary to determine the amount of permanganate which is instantly used up in the cold. This instantaneous value determines the hydrogen sulphide, ferrous salts, and other products of reduction accompanying anaërobic fermentation, and includes also the nitrites, if any are present. After correcting this value for the nitrites, any marked increase after incubation is indicative of putrefaction having taken place. The determination of the free oxygen and the nitrates after incubation will be unnecessary unless it be desired to distinguish between Class 1 and Class 2*a* as described. In the writer's opinion no such separation is necessary, since effluents of either class are either stable or will rapidly become so. In fact, it is only effluents of the highest degree of purity which will fall into Class 1. Such effluents will, as a rule, be produced only when necessary for the protection of water supplies, and in such cases a much more delicate test, such as the bacteriological examination, would naturally be relied upon.

It will be observed that the conditions established by these incubation tests correspond with the three conditions defined by Rideal's formula (page 126), the difference lying in the way in which the oxygen required for complete oxidation is determined. The use of such a formula as a substitute for the incubation test would be highly desirable. It must first be shown, however, that the oxygen consumed from permanganate is practically the same as that used up during incubation. Obviously by boiling for four hours with permanganate a much greater amount is used up than would be required by the effluent to render it stable. The Lawrence method of boiling for two minutes would probably give deficient values. This is a point worthy of further study, since it determines at once the most important character of the effluent — its stability.

FILTERED AND UNFILTERED SAMPLES. TURBIDITY, COLOR

In effluents showing an appreciable turbidity, the determination of the total nitrogen upon the sample after filtration through paper will give additional information. Since it may be assumed that a large part of the suspended solids will eventually find its way to the bed of the stream, this information will be of practical value to the analyst. The writer has found the determination of the putrescibility upon such a filtered sample to be also of service. In some cases a mere settling out of the grosser matter will serve to change the character of the effluent from one slightly putrescible to one thoroughly satisfactory. As a measure of the absolute amount of suspended matter in the effluent, a quantitative reading of the turbidity as described in an earlier paper will be of service.

The color of clear effluents of high purity often serves as a useful indication of slight changes in the work of the filter. Where a high degree of purification is not attempted the color of the effluent is of no value whatever.

The odor of the effluent is often of significance to the analyst, although the difficulty of correctly describing such an odor in intelligible terms lessens the value of this test as a matter of record. The writer has used a set of terms for odors in sewages and effluents which are sufficiently self-explanatory to any other analyst engaged in the same work to render them of some service. They are as follows: *Sewage*, the odor of fresh sewage as it flows in a city sewer, especially in winter. *Septic*, the characteristic odor of septic sewage, which often persists after passage through the filter. *Musty*, as used in water analysis; generally characteristic of contact filters. *Earthy*, the odor of fresh, clean earth, characteristic of trickling filter effluents. *Vegetable*, as used in water analysis, characteristic of well-purified sand-filter effluents. The numerical expression of the intensity of the odor, as recommended by Whipple (1901), is used in connection with these terms with fairly satisfactory results. The odor after incubation is obviously of great value in the interpretation of that test.

BACTERIA

When we consider that the removal of pathogenic organisms from the sewage is one of the prime reasons for its purification, it is unfortunate that the advance of knowledge in this particular subject has been very much slower than on the purely chemical and engineering sides. The actual removal of pathogenic organism from water by sand filtration has been experimentally demonstrated, and a study of the vital statistics of certain localities before and after purification of a polluted water supply leaves no room to doubt that a fairly complete removal of such organisms by sand filtration is possible. It might thus very well appear that in the case of sewage a careful purification through sand filters, which reduces the total bacteria to a figure permissible in a filtered water supply, will also have effectively removed the pathogenic forms.

The organisms supposed to be the cause of nitrification in the filters have been extensively investigated. Qualitative studies other than these are not very often made. What little information exists at present on this important subject is for the most part too meagre to allow of any general conclusions as to the significance of any given organism or groups of organisms in an effluent. One important exception to this statement, however, must be made in the case of the organisms *Bacillus coli* and *B. enteritidis.* The occurrence of these two organisms in the effluents of sewage filters has been made the subject of an extensive study by Houston and McGowan (1902), who show that in a series covering a wide range from raw sewage to completely purified effluents the unpurified organic matter of the effluent is roughly proportional to the numbers of colon bacilli, to the numbers of *B. enteritidis*, and to the numbers of organisms producing gas in sugar gelatin. As a practical test they have selected the latter group of organisms, whose approximate numbers can readily be estimated by the dilution method. The practical standard of purity proposed is that the effluent shall not contain over ten of these gas-producing organisms per cubic centimeter. In the extensive comparison made this standard in every case served to distinguish between the satisfactory and unsatisfactory effluents.

Another important line of work has been indicated by Clark and Gage (1905). These investigators have found that a large percentage of the total number of organisms passing through a sewage filter consists of a relatively small number of species. These species are carefully counted on the gelatin plate, and a number of each kind fished for further study. In this study the ability of each organism to liquefy gelatin, ammonify peptone, oxidize ammonia to nitrites and nitrates, and to reduce nitrates to nitrites, ammonia, and free nitrogen is determined quantitatively. The quantitative power of any organism to produce ammonia from peptone times the number of organisms of that kind present in a cubic centimeter of the effluent is the ammonifying power of that organism in the effluent. The sum of the ammonifying powers of all the organisms present constitutes the ammonifying coefficient of the effluent. Similar coefficients are determined for each of the other functions mentioned. It is too early to venture an opinion upon this work. Since, however, we are dealing with life processes, it would seem that the proper method of determining the properties of an effluent would be a study of the life within the effluent and the chemical changes which the living organisms are capable of producing, or what the authors aptly term the "biochemistry" of the effluent.

Mere quantitative counts of the organisms in the effluent are of no significance except in those effluents in which a high degree of purity is expected. In such cases the number of organisms present serves as a valuable index of the amount of organic matter in the water.

OTHER PROPOSED TESTS

Many other tests of minor importance have been proposed for the rapid determination of the character of the effluent. Such tests for the most part lack the merit of being based upon any scientific principle, and are, as a rule, only used for the guidance of the workmen in the control of the filter plant.

At Leeds, England (Harding, 1902), the effluents are passed through small basins in which fish are kept. The fact that fish are thus able to live is taken as evidence that the effluent is satisfactory. Obviously the ability of fish to live in an effluent signifies merely that there is an abundant supply of oxygen and an absence of any great amount of turbidity, facts which could be equally well shown by very simple tests.

In these same basins certain microscopic animals and plants are often found, and upon the character of such growths Walker (1902) has based an interesting biological test for the quality of the effluent. For example, he found that the best effluents, such as those from double contact systems high in nitrates, support a copious growth of the *Chlorophyceæ*, notably *Stigeoclonium* and *Microspira*, while *Oscillaria* and other *Cyanophyceæ* are generally present in small amounts or altogether absent. In slightly inferior effluents these blue-greens predominate, together with *infusoria* and *rotifers*. Still poorer effluents were found to be characterized by the presence of *Beggiatoa* and the infusoria, *Carchesium* and *Vorticella*.

The Derbyshire County Council recommend a "shake test." In this test the effluent is vigorously shaken in a bottle for one minute. In a satisfactory effluent the froth should disappear within three seconds. The significance of this test is not apparent.

Barwise (1904) suggests that the process of purification is accompanied by the conversion of ammonium carbonate into nitrous and nitric acids, a change from alkaline to acid reaction. He therefore recommends the determination of the alkalinity in the raw sewage and in the effluent as a measure of the purification. In sewages containing much cellulose, however, he found the test to be unreliable on account of the production of acids from the cellulose.

SUMMARY AND CONCLUSION

Summarizing briefly the most important points in the analysis of a sewage-filter effluent, it may be said that the determination of the nitrogen in all its forms is of first importance, not alone in indicating the extent of the purification, but as an index of the stability of the effluent; that the determination of the total organic carbon, or its roughly relative estimation by the oxygen-consumed test, ranks next in significance, representing material that still requires oxidation; that the dissolved oxygen is of great significance both as to the condition of the filter and the stability of the effluent; and that a study of the changes occurring during incubation serves to reënforce the analytical data, and is in reality the ultimate criterion upon which the interpretation of such data depends. The value of bacteriological data as indicative of the quality of the effluent is still an unknown quantity, although the writer is inclined to believe that the determination of specific coefficients, as described by Clark and Gage, may eventually become the standard against which we may check our simpler laboratory methods. Such extensive studies are obviously not available in the routine work of the analyst for sewage works, but are of the greatest importance in enabling us to understand the processes with which we are dealing and correctly to interpret our analytical data.

In the following specimen analysis of an effluent are included the important determinations which have been described in the preceding pages.

Specimen Analysis

(Parts per million)

	Total.	Dissolved.	Suspended.	After incubation. Five days at 37°.
Nitrogen:				
Total	50.5	44.5	6.0	. .
Organic	16.0	10.0	6.0	. .
As NH_3	11.0	11.0	. .	. .
As N_2O_5	1.5	1.5	. .	1.0
As N_2O_3	22.0	22.0	. .	15.0
Carbon:				
Total	100.0	70.0	30.0	. .
By $KMnO_4$:				
Cold. Instantaneous	0.1	. .	.	0.1
Three minutes	0.6	. .	. .	0.4
Hot. Thirty minutes	12.4	8.0	4.4	. .
Oxygen:				
Dissolved	7.2	. .	. .	5.0
Turbidity:				
Total	125.0	. .	. .	. .
On standing	25.0	. .	. .	. .
Sediment (diff.)	100.0	. .	. .	. .
Color	. .	. .	. .	. .
Odor	3 earthy		. .	1 musty

REFERENCES

Adney, 1902. Interim Report of the Royal Commission on Sewage Disposal, II, Quest. 2425.

Barwise, 1904. The Purification of Sewage, London, 1904, p. 77.

Clark, 1900. Thirty-first Annual Report of the Massachusetts State Board of Health for 1899, Boston, 1900, pp. 422, 424.

Clark and Gage, 1905. The Functions of Various Types of Bacteria in the Purification of Sewage with Some Methods for Their Quantitative Determination, Eng. News, LIII, p. 27.

Eddy, 1901. Annual Report of the Superintendent of Sewers, Worcester, Mass., year ending Nov. 30, 1901, p. 46.

Fowler, 1901. Annual Report of the Rivers Department, City of Manchester, year ending March 27, 1901, p. 30.

Frankland, 1902. Interim Report of the Royal Commission on Sewage Disposal, II, Quest. 3059.

Fuller, 1903. TECH. QUART., XVI, p. 132.

Gayon and Dupetit, 1886. Station Agronomique de Bordeaux, 1886.

Great Britain, 1861. Parliamentary Accounts and Papers.

Great Britain, 1872. Fourth Report of the Royal Commission on Rivers Pollution, I, p. 104.

Harding, 1902. Interim Report of the Royal Commission on Sewage Disposal, II, Quest. 7403.

Houston and McGowan, 1902. Interim Report of the Royal Commission on Sewage Disposal, II, p. 326; see also accompanying chart in same report, III.

Kinnicutt and Eddy, 1901, 1902. Third and Fourth Reports of the Connecticut Sewerage Commission.

Phelps, 1905. The Interpretation of a Sewage Analysis, TECH. QUART., XVIII, p. 40.

Phelps and Farrell, 1905. The Mode of Action of the Contact Filter in Sewage Purification, Jour. Inf. Dis. 1905, Supplement No. 1, p. 229.

Rideal, 1902. Interim Report of the Royal Commission on Sewage Disposal, II, Quest. 4161.

Scudder, 1902. *Ibid.*, Quest. 5988.

Walker, 1902. *Ibid.*, Quest. 7402.

Whipple, 1901. Amer. Pub. Health Ass'n, Reports and Papers, XXVII, p. 380.

Woodman, 1898. A Method for the Differentiation for Organic Matter in Water, Jour. Am. Chem. Soc., XX, p. 497.

A WINTER VISIT TO SOME SEWAGE DISPOSAL PLANTS IN OHIO, WISCONSIN AND ILLINOIS.

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[Read before the Sanitary Section of the Society; April 5, 1905.]

We must go west in order to learn the new things in sewage purification. In New England the classic Lawrence experiments of 1890 have firmly grounded our theory, and the mantle of glacial drift makes our practice easy. Beyond the range of the Appalachians all is changed. The character of sewages and the available materials for treating them are alike different. Old England rather than New England furnishes comparable conditions and we find a general development of the newer British processes through the Mississippi Valley. Even these methods, however, prove not wholly suited to their new conditions. Many of them are failures, on account of climate, on account of varying sewages, on account of the political conditions which make it difficult to secure efficient public service in American municipalities. No saying, however, is more true than that "We learn by making mistakes." They are learning a great deal in Ohio and Wisconsin and Illinois about the rapid methods of sewage purification. Columbus is doing for such processes what Lawrence did for sand filtration fifteen years ago. The whole region is an inspiring one for the sanitarian to visit.

In a short trip through the Middle West during January of the present year I had the opportunity of seeing some dozen sewage purification plants of various types under the most unfavorable conditions of practical operation, and I have been asked to tell you what I saw, in the hope that even such a fragmentary report may help us to estimate the success of the newer processes of sewage treatment in this country and their promise for the future.

From the admirable report by R. W. Pratt on Ohio sewage plants in 1903 it appears that there were then eleven sand filter plants in the state of Ohio, with which no sort of preliminary treatment was used. One was a subsurface system; one was wholly, and two were partly, given up to broad irrigation. All but three were small plants serving institutions, and the total population connected with the eleven plants was only 21 000. One of the best of these intermittent filters is that at the Ohio State

Reformatory at Mansfield, O. (Pratt, 1905). The sewage from a population of six or seven hundred persons, amounting to 60 000 to 70 000 gal. per day, is discharged on seven small beds with a total area of 1.1 acres. The beds are built of friable sandstone taken from a cliff near by and crushed by the prisoners. The effluent is said by the engineer of the State Board of Health to be of good quality, but considerable trouble has been experienced in keeping the beds clear in winter. They were originally plowed with deep furrows 1.5 ft. high, and 4 ft. apart, but this worked badly, as the available area was unduly decreased and the beds froze. At the time of my visit small furrows 6 in. high were giving poor results, the beds being half frozen and covered with slush. Probably a judicious mean might prove more favorable.

The only other intermittent filtration plant I saw in the West illustrated the difficulties which attend this process where ample areas of sand cannot be obtained. Oberlin, O. (Pratt, 1905), is a village of 5 000 inhabitants lying 30 miles west of the city of Cleveland and 10 miles from the shore of Lake Erie. The first sewers were constructed in 1892 and two years later a field in the outskirts of the town was laid out for sewage disposal. Six acres of fine sandy loam were available to receive gravity flow, of which three acres and a half were underdrained for intermittent filtration and an acre and three-quarters merely ditched for broad irrigation. Two settling basins, 3 ft. deep and 10 ft. by 30 ft. in area, were constructed by excavating pits and boarding up the sides, and from these the sewage overflowed through distributing ditches on the beds. Sludge from the pits was pumped out and dumped near by; it amounted to some 4 per cent. of the sewage treated. For some years the plant worked well while the average flow of sewage remained below 100 000 gal. per day. Since 1902, however, it has rapidly increased, to some 250 000 gallons at the present time, and the beds have become heavily overtaxed. In order to prevent serious pollution of the creek below, the system has been converted into a sort of chemical precipitation plant by a process probably unique in the history of sewage purification. During the warmer nine months of the year chemicals are discharged into the main sewer of the town, about 125 lb. of ferrous sulphate and 150 lb. of lime in the form of hydrate, by automatic devices located respectively at the upper end and the middle of the system; sedimentation takes place in the pits and on the beds which are generally clogged and a considerable nuisance is created. At the time of my visit in January no chemicals were being used and the sewage was simply standing on the beds and overflowing into the creek, turning the whole area into a noxious swamp.

The reason for the failure of this Oberlin plant is, of course, the absence of a sufficient area of land really suitable for intermittent filtration. In this respect it is fairly typical of general conditions throughout the Middle West. Sand treatment alone is inadequate over most of this great region; and it has been necessary to seek some preliminary process which should make possible filtration at more rapid rates. As in England, chemical treatment first suggested itself for this purpose and a number of plants have been installed, somewhat less crude than the one just described. Glenville, O., has chemical treatment preparatory to passage through the contact bed, and at Alliance, O. (9 500 population), and Canton, O. (32 000 population), chemical precipitation is the only method used. Both the latter plants are said to be well operated and to yield fairly satisfactory results (Pratt, 1905).

As in other localities, however, the disadvantages of the chemical treatment have been made manifest. Poor effluents, offensive sludge and costly operation prove almost inseperable from this method. It was natural, therefore, that engineers should turn their attention to some better method for removing suspended solids. It soon appeared that such a method could be developed by the regulation of the anaërobic ripening process which goes on in every cesspool. Such a preliminary ripening liquefies a considerable portion of the solid material in sewage. According to its advocates it does the work of chemical precipitation without the cost of chemicals and with a diminution of objectionable sludge. As championed by Donald Cameron of Exeter, who gave it the picturesque name of the "septic tank," this anaërobic process seemed most promising; and nowhere has it been more cordially received than in the Middle West. Indeed, there may almost be said to be a cult of the septic tank in Illinois and Wisconsin. Even in small towns where no system of sewage purification is really essential the possession of a septic tank is a matter of municipal pride; in some half dozen towns this is the only method of treatment, the clarified effluent being discharged into the nearest body of water without any attempt at nitrification.

I saw one such system at Highland Park, a lake shore suburb of Chicago with a population of about 4 000. Two-thirds of the village drains westward and the sewage from this region has been treated for some years by the septic tank method. The new tank which I saw in operation was put in by W. S. Shields only three months ago, and takes a portion of the sewage from the eastern part of the village along the lake front. Two other outlets from this region discharge into the lake without treatment. The tank is covered and underground and in somewhat close proximity to the pumping station of the waterworks. At the time of my visit its effluent contained considerable suspended matter, but as the tank had been in operation for so short a time and during cold weather it could not have attained its normal condition. With regard to the wisdom of treating sewage by the septic tank alone without a subsequent aërobic process, I must confess myself somewhat skeptical. There may be cases where raw sewage would cause a nuisance, while the clarified septic effluent is sufficiently improved to do no harm; but such a balance of conditions must be rare.

In general, of course, the septic tank treatment is only used as a preliminary to intermittent or contract filtration, and on these principles many admirable plants have been constructed and are in operation in the Middle West. Of the first type I saw three good examples, one at Lake Forest, Ill., and two at Wauwatosa, Wis. The Lake Forest plant was designed in 1902 by J. W. Alvord and W. S. Shields (Alvord, —) to care for a flow of 350 000 gal. a day. A population of 1 800 at that time has now increased to about 3 000, and it is probable that the plant is nearing its full capacity. It is beautifully located at the bottom of a bluff on the shore of Lake Michigan. The sewage first flows through an open brick septic tank protected from abrupt temperature changes by a light brick structure and divided into five compartments so arranged that by various combinations the period of septic action may be adjusted to suit varying conditions. (Fig. 1.) Mr. Alvord has pointed out the desirability of so building tanks that the period of fermentation may be altered with changes in temperature and in the volume and composition of the sewage; and most of his recent septic plants are built upon this principle. The theory, upon which this practice rests, is that a too brief period fails to remove a maximum of solid material while over-prolonged septic action produces an effluent which is for some reason hard to nitrify. It is, unfortunately, almost impossible to secure proper expert supervision of sewage disposal under present conditions, and at all the plants which I visited the operation of the "elastic tank" had been practically abandoned and the whole available area was used as a single tank.

At Lake Forest with a tank 35 ft. by 20 ft. in area and 8 ft. deep, and a capacity of 50 000 gal., this method of operation gave a period of about four hours. One-third of the tank back of the first baffles was covered with a very heavy layer of frozen scum while the rest of the tank showed only half an inch of light scum. The effluent from the tank which runs over an aerating weir into a dosing chamber of 7 000 gal. capacity, appeared to be a good septic sewage, dark colored and with only very fine suspended particles. The tank has never been cleaned out.

One important feature of the western sewage plants is the genetal attempt to introduce automatic devices for regulating flow and for dosing filter beds. The danger from the failure of such devices is, of course, always considerable and they absolutely require periodic expert supervision; but by and large I am inclined to think even a fair automatic device will prove as reliable as the average city employee. The apparatus used at Lake Forest for dosing the sand filters is an extremely ingenious one. A float in the dosing chambers lifts a cannon ball in one of a set of hollow wooden columns arranged in series, and at a certain height the ball rolls through a trough from one column to the next, in its passage striking a catch which opens an air valve attached to one of ten bell syphons in the dosing chamber. Each syphon discharges on one of the ten sand filters which may thus be dosed in rotation. At the time of my visit the automatic device had been purposely thrown out of gear so that the sewage was flowing continuously upon one bed, perhaps with the idea of preventing the surface from freezing.

The sand filters are each 3 200 sq. ft. in area, the total area being three-fourths of an acre, and the rate is therefore now over 400 000 gal. per acre per day. The filtering material, the natural beach sand of Lake Michigan, is quite fine, 85 per cent. passing a sieve with 40 meshes to the inch, and 42 per cent. passing a sieve with 60 meshes to the inch. The distributing carriers used here and elsewhere by Messrs. Alvord and Shields struck me as admirable, — for small beds superior, perhaps, to those which are more common in the East. They are straight or branched troughs made of two upright sides of 2-in. plank, resting on a similar bottom plank with 3-in. square holes at the base of the sides, spaced about 2 ft. apart. Like all distributing devices their operation requires sufficient head to yield a good gush of sewage; given this they should be perfectly satisfactory.

With the dosing device deliberately thrown out of operation, as I have mentioned, the Lake Forest plant was not doing wholly satisfactory work. Sewage was standing several inches deep on the one bed which could receive it, and the effluent as it flowed off to the lake was dark colored and appeared imperfectly purified.

A plant very similar to that at Lake Forest was built four years ago by Alvord and Shields for the town of Wauwatosa, Wis. (Alvord, —). The population of the town is about 3,000, but there are not more than 200 connections with the sewer system, including a sanatorium, a pickle factory and a chemical works. The flow is said to be about 100 000 gal. a day. The sewage first enters a concret septic tank sheltered as at Lake Forest by a brick roof. The tank is approximately 15 ft. by 50 ft. by 10 ft. deep, with a capacity of 40 000 gal. It was originally provided with three longitudinal partitions, but the sewage is now run straight through, giving a storage period of 10 hr. At the time of my visit the first tenth of the tank behind the first baffle bore 6 in. to 8 in. of very heavy scum, and a considerable accumulation of sediment could be felt at the bottom. The town engineer informed me that the tank must be cleaned out twice a year, a quantity of combined scum and sludge equal to half its capacity being removed by dipping out with pails and by the use of a small rotary pump. The effluent appeared like a good septic sewage, dark gray in color and with no large particles.

The septic effluent should pass to a dosing chamber in a separate small brick structure where it may be discharged on sand beds by the same device in use at Lake Forest. (Fig. 3.) The beds are 6 in number, 30 ft. by 60 ft., with a combined area of one-fourth acre, thus giving a rate of 400 000 gal. The sand used is coarse and the results obtained are said to be excellent. In cold weather, however, it is the practice of the authorities to discharge the septic effluent directly into Menominee Creek without filtration. This has not been compelled by any failure of the plant, but is done to avoid the expense of caring for the surface of the beds during a season when the septic tank effluent will not produce a serious nuisance in the river below. Like the use of storm overflows such a custom does not commend itself to the sanitarian; but from the standpoint of the city engineer it may be good economy.

In the same town is a larger plant of almost exactly similar construction (Shields, 1904), which shows what good results can be obtained by careful and efficient operation. The Wauwatosa County Institutions form a group of five buildings, including two insane hospitals, an almshouse, a county hospital and a home for dependent children. The total population is about 3 500 and the water consumption, 400 000 gal. per day. A chemical precipitation system was put in in 1888, the dosing house and coagulating basin still remaining as its monument. Then a septic tank alone was installed; but it proved unsatisfactory, and about a year ago Mr. Shields built a new septic tank and filter beds. It is planned to use the old tank as a part of the septic system in the future, but at the time of my visit the sewage was flowing only through the newer one. This is 86 ft. long, 20 ft. wide and 8 ft. deep with a central longitudinal partition and 3 concrete baffles. The first two compartments, making up about a third of the tank, bore a thick frozen scum raised by gas pressure 6 in. above the surface of the liquid. At the outlet as it ran off over an aërating weir, the effluent appeared a strong septic sewage still containing a fair amount of suspended matter. The storage period under present conditions appears to be 6 hr. With the addition of the old septic tank, 8 ft. by 17 ft. by 54 ft., it would be increased to 9 hr. Both tanks are of concrete, housed under low brick buildings with gabled roofs.

From the septic tank the sewage flows through an inverted siphon to the filter beds which are located on the further side of a small stream. The beds are eight in number, arranged in two rows with a controlling house in the centre. (Fig. 2.) The four corner beds are each 50 ft. by 110 ft., while the four centre beds are 57.3 ft. by 55 ft., being shortened to provide room for the distribution system. The latter is of the general pattern described above, including a dosing chamber discharged by any one of eight 15-in syphons, each connected with one bed. The rotation of the beds is controlled automatically by a cannon ball device quite similar to that used at Lake Forest.

The filter beds are built up of 12 in. of coarse gravel, 12 in. of fine gravel and 12 in. of coarse sand, and are underdrained by four lines of 4-in. pipe. The carriers are of the usual type, two straight troughs in each bed with 3-in. square holes about 2 ft. apart.

The plant is carefully supervised by the superintendent of the institution, and was working in admirable shape when I saw it. The siphons flush perhaps once every 35 min. in the morning, every 45 min. in the afternoon, and once an hour at night, so that each bed is dosed once in from 4 to 8 hrs. The total area is about 1 acre for the 400 000 gal. treated.

In spite of severe weather in January the dose disappeared in twenty minutes after its application; but at intervals it is necessary to rest a bed for a few days by putting into the cannon ball regulator a chute which shall shut out one of the dosing siphons. The effluent from the plant as I saw it floating into the Menominee Creek was clear and well purified.

It is only rarely that such plants as those at Wauwatosa can be installed in the West, for the use of larger communities, since, even after preliminary septic treatment, the requisite sand area is generally unobtainable. Hence, the newer English types of filters have been frequently adopted; and we find the septic tank and contact filter the most popular of all combinations through Ohio and Iowa. A dozen systems of this type are installed in these states, with an aggregate contributing population of 60 000. Mansfield, O. (20 000), Marshalltown, Ia. (11 000), Delaware, O., and Kenton, O. (each 8 000), are the largest cities in this class.

The disposal system at Mansfield (Pratt, 1905), built by Snow and Barbour, three years ago, is one of the most perfect of this type as well as the largest. The town is a thriving farming and manufacturing centre with a population of 20 000. About half the inhabitants contribute sewage, the total amounting to 1 000 000 gal. per day. The purification works, about three-fourths mile from the centre of the city, and with dwellings not an eighth of a mile away, is as neat as a pin, from its well-kept driveways and embankments to the spotless engine room with a row of potted plants in the window. The sewage flows by gravity to a sludge well from which it is raised by two 7-in. centrifugal pumps to the septic tanks. Both tanks and sludge well are ventilated by connection with the stack from a Dixon crematory in the pumping station which handles the city garbage, amounting to 15 to 20 tons a day.

The septic tank is an arched concrete chamber covered by an artificial mound, its presence being indicated only by the manhole covers. It is built in four compartments, each 50 ft. by 100 ft. and 7 ft. deep with a total capacity for the four of 1 000 000 gal. The sewage flows now through all in parallel, the period of septic action being twenty-four hours. In the three years of their operation these tanks have never been cleaned, and the superintendent informed me that not more than 1 in. of sediment and 2 in. of light scum have ever formed. Comparison with some of the tanks descsibed above suggest that perhaps the longer period of septic action has had some share in these excellent results.

From the septic tanks the sewage flows over a series of aërating steps (Fig. 4), and thence to the regulator house situated in the center of a circular group of five contact beds. The automatic dosing device consists of two concentric iron cylinders about 2 ft. in diameter, the outer one stationary and pierced by five ports, one for each bed, the inner one revolving so as to bring its single influent port successively opposite each of these five points of discharge. A float, regulated by the height of sewage in whichever bed is filling, at a certain height starts the inner cylinder, closes the outlet from the bed next to be filled and opens the outlet of the bed which has stood full since the last revolution. Each of the beds has an area of one-fourth acre and is filled with one-eighth in. to one-half in. cinders to a depth of 5 ft. The period of contact is about 4½ hr. and the rate of treatment 800 000 gal. per acre per day.

At the time of my visit the beds had been out of use for two or three days during the process of cleaning out part of the low level sewer system, as it was feared the silt might damage them. The septic effluent was going straight to the nearby stream. I was informed by the superintendent that this had occurred only once or twice before during the operation of the plant. The surface of the beds seemed in admirable condition and the effluent of the plant, according to the analysis published by Pratt (1905), is generally excellent.

I was somewhat unfortunate in my experience with contact beds during my trip. Of five plants of this type, that at Mansfield was temporarily out of operation on account of what seem to me quite legitimate reasons. In two others the automatic dosing devices were so frozen up that the beds were not being dosed at all; and a fourth had been entirely abandoned as a nuisance. Only one, that at East Cleveland (Pratt, 1905), was running properly; and this plant is of so peculiar a type that it can hardly be said to operate on the contact plan at all. The flow through three successive rows of slag beds is continuous for a period of several days, air being supplied by forced aëration on the Waring plan; but perhaps this plant may be considered more nearly allied to the contact bed than to any other system.

East Cleveland is a town of 6 000 inhabitants lying near the shore of Lake Erie, just east of the city of Cleveland. The larger part of this population contributes sewage, the total amounting to some 400 000 gal. It is said that this amount is trebled by leakage and surface drainage at certain times of year. At the disposal area the sewage flows first to an open receiving well where a considerable amount of solid matter settles out, the accumulated sludge being pumped out twice a week, mixed with lime and dumped on land near by. The supernatant sewage is pumped from the well to a septic tank, 87 ft. by 24 ft. and 11 ft. deep, covered by a wooden pitched roof. The period of septic action is 10 hr. or less. Pratt (1905) states that after a year's operation about a foot of sludge was taken from this tank. At the time of my visit a heavy cheesy scum, 6 in. in thickness, covered the whole tank and the effluent was markedly turbid. It may be that the period of septic action is too short or that the storm water brings in material not easy to handle; but certainly this tank seems much less successful than others. No problem in sewage disposal is more puzzling than the question why one septic tank succeeds and another fails. Mr. Alvord (1902) strongly maintains that tanks which are too large as well as tanks which are too small tend to fill up, and considers 4 to 8 hr. a proper fermentation period. Shields (1904), on the other hand, recommends that septic tanks should have a capacity of not less than three-fourths of the daily flow.

Certain English experiments seem to indicate that a variation from 12 to 48 hr. makes little difference. It is *a priori* difficult to understand why long periods of septic action should increase sludge deposits. If flow is so rapid that solid particles have not time to settle out or if accumulation of sludge goes on faster than its dissolution, bad results may follow. But with slow flows the processes of liquefaction should have the best chance to do their maximum work, and sludge ought not to accumulate; although here the possibility must be recognized of septic changes in the sewage itself which may be inimical to bacterial action in later processes.

From the septic tank the sewage at East Cleveland flows through three sets of beds filled with 2.5 ft. of coarse slag, of egg-coal size, passing downward through the first, upward through the second and downward through the third. Air is forced into the spaces under each bed by aërators shown in the figure. (Fig. 5.) With the aid of this aëration it was hoped that some of the organic matter could be nitrified and the rest strained out by the slag and finally oxidized by allowing the beds to stand empty for a period at frequent intervals. At present each filter is run for three days and then rested for the same period. The plant is said to give good results in summer, but at the time of my visit it was noticeably offensive in odor, and the effluent was turbid and imperfectly purified. The use of forced aëration seems a doubtful expedient in sewage purification when one considers the large amount of oxygen consumed by sewage in a trickling filter, for example, and the impossibility of supplying such an amount by any practicable mechanical system. The use of the beds for continuous three-day periods also seems unwise. The total filter area of half an acre, if laid out in contact beds somewhat deeper than those now in use and operated in the usual manner, should be able easily to handle the flow of 400 000 gal. daily.

A short distance north of the East Cleveland plant a smaller contact system is installed at the Lake Shore & Michigan Southern Railroad Car Shops in the thickly settled portion of the village of Collinwood (Pratt, 1905). The sewage of 500 operatives flows to a pump well from which it is automatically raised at intervals by a pump driven by compressed air and discharged into two septic tanks, each 21 ft. by 10 ft. by 9 ft. deep, with a capacity of 25 000 gal. When the sewage in the septic tanks reaches a height of 8 ft. they are supposed automatically to discharge the upper 2.5 ft. into four contact beds, concrete basins, each 15 ft. by 29 ft., filled with 5 ft. of 2-in. limestone. On filling, the beds discharge through siphons. The plant is a neat and compact structure with brick walls and plank covering and is supposed to operate entirely without supervision. At the time of my visit all the automatic devices were frozen, the pump was not working, the septic tank contained a thin but foul stagnant liquor and the sewage was apparently flowing off through a by-pass. Such must infallibly prove the fate of automatic devices if their automaticity is construed literally and they are left entirely without supervision.

The fourth contact filter which I visited was at Glencoe, Ill., a suburb of Chicago lying on the northern lake shore between Highland Park and Evanston. It has a population of 1 500, about two-thirds contributing sewage to the system. The Cameron Septic Tank Co. installed a plant some three years ago consisting of a septic tank and double contact beds. Like that at Lake Forest it is located on the shore of the lake and hidden from the town by a high bluff, but in general appearance the plant is sufficiently attractive to be displayed rather than hidden. It consists of a covered concrete tank some 80 ft. long and 10 ft. wide, a set of four primary contact beds with a combined area of about 1 200 sq. ft. and a similar battery of secondary contact beds at a level about 4 ft. lower. On the lower beds are two neat brick regulator houses which contain a complex arrangement of floats and cranks for the automatic control of the beds. (Fig. 6.) The material in the beds is said to be slag, but on the half frozen surface there seemed to be a considerable admixture of rather fine gravel and cinders. According to the City Clerk, the plant worked well for a time, but gradually became a nuisance to the neighborhood, being offensive all through 1904. Last fall the beds became so clogged as to overflow continuously and the plant was abandoned, the sewage being discharged directly into the lake.

I am inclined to think that the conditions in these last two plants are due to difficulties inherent in the contact system of sewage purification as applied to small plants. The process is a complex one involving successive aërobic and anaërobic fermentations which must be delicately adjusted. With the lack of supervision which is almost inevitable in a small disposal system, automatic devices will fail and filters will be thrown out of operation or overdosed so as to cause clogging. The slow sand filter and the trickling filter, being simpler in theory and easier of regulation in practice, are much better fitted for installations liable to be left to themselves for days and weeks at a time.

A plant with a sufficient excess of capacity may, of course, give fair results even when neglected; and a good example of this is furnished by the system at Westerville, O. This village, a few miles northwest of Columbus, has 1 500 inhabitants, but not more than 100 persons are connected. The daily flow is from 20 000 to 25 000 gal. and includes the waste from a creamery, which introduces a large amount of refractory organic matter from the washings of the cans. The sewage first flows through a pair of septic tanks, each 8 ft. by 26 ft. in area and 8 ft. deep, with a combined capacity of about one day's flow. The tanks are of concrete, covered with planking, and appear to do good work, the sewage as it enters being strong and turbid, the effluent clear and free from suspended matters. On leaving the tank the effluent passes through an aërating chamber in which it flows over three iron discs of successively increasing size, the lowest being 2 ft. 6 in. in diameter. It is then passed through six primary contact beds, each with an effective area of 0.021 acre, containing 3 ft. of screened cinders, one-eighth in. to 1 in. in diameter, and finally through two secondary filters, each 13 ft. sq. at the bottom and 31 ft. sq. at the top, containing 6 ft. of cinders. (Fig. 7.) The primary beds are dosed by two devices, each of which consists of a perforated bowl resting ball-and-socket fashion in an upright influent pipe and overflowing through three trough-like arms to the various beds. At the time of my visit the devices were out of order and the sewage was trickling continuously on four of the beds, forming a pool on the surface 6 ft. in diameter which an abundant growth of Leptomitus shows to be fairly permanent. Pratt (1905) in his description of these beds notes the same conditions. The primary beds should be discharged on the secondary beds by siphons, each one operated by the height of sewage in the adjoining bed. These devices, too, were inoperative and sewage was steadily dribbling on, so that both sets of beds were working like trickling filters, but, of course, with the most incomplete sort of distribution. The pools on the upper filters were somewhat offensive and the odor of the plant was noticeable several hundred feet away. The effluent standing on the secondary beds was much less disagreeable and the final effluent below the plant, clear and odorless. With such a low rate of filtration (200 000 gal. per acre per day on each set of beds), even this neglected system was yielding fair results.

In actual operation the Westerville plant was acting like an imperfect sort of trickling filter; but there are *bona fide* systems of this type in the Western States which are of very special interest. The largest trickling filter, I believe, is the one which handles the sewage of the 20 000 people of Madison. I did not see this, but I found a smaller plant installed at the car-shops of the Allis-Chalmers Co. at West Allis, just out of Milwaukee. This plant, designed by Mr. Shields in 1902 to care for 80 000 gal. of sewage per day from the large factory in which 3 500 men are employed, is located on a hillside behind the works and consists of a concrete septic tank and anaërobic filter covered with a gabled roof and a trickling filter under a second roof and at a lower level. The open septic tank is divided by a central partition into two long tanks, each 10 ft. by 58 ft. and 7.5 ft. deep, the total capacity being 65 000 gal. or 18 hr. flow. Below the tank the sewage is aërated by fall over a weir and some steps and then enters the anaërobic filter, so called, which is practically a second septic tank, 21 ft. by 33 ft. long and 7.5 ft. deep, filled with clinker and cinders in graded layers. After flowing upward through this tank the sewage passes to three 8 ft. by 5 ft. siphon chambers which discharge it on the trickling filter below. This filter is practically a pile of cinders and clinker, varying from 0.25 in. to 0.75 in. in diameter, held together by larger clinkers on the outside, piled with a slight batter. The height of the heap is 7.5 ft. to 8 ft., its superficial area, 30 ft. by 54 ft., and the concrete floor upon which it rests is 40 ft. by 60 ft. Considerable trouble has been experienced from disintegration of the clinkers. In winter, as I saw it, the sides of the filter were closed in by plank walls; but in warm weather the whole is open. (Fig. 8.) The distribution system is very simple, consisting of three 12-in. plank troughs with 4-in. lateral troughs in the bottom of which 0.25-in. slits are cut at a distance of 8 in. apart. Each siphon discharge floods one main trough with its laterals, and the distribution as I saw it appeared satisfactory.

The general design of this plant seems admirable, the only part of it to which I should take serious exception being the anaërobic filter. According to the designer (Shields, 1904) its object is "to produce conditions under which the facultative bacteria can do their work and prepare the effluent for more rapid nitrification in the aërobic filter." An action of this sort is very hypothetical. We have little proof that septic action favors subsequent nitrification aside from the removal of suspended solids and some evidence that if prolonged it may seriously hinder it. Furthermore, filling up a septic tank with stone makes the difficulty of cleaning so serious that the extra straining capacity is dearly bought.

Mr. Shields states that the actual flow of sewage at the plant has been much greater than that for which it was designed, reaching a rate of over 300 000 gal. per 24 hr. for 12 hr. of the day. No trouble has been experienced from freezing, and the trickling filter has been operated at a rate of over 3 000 000 gal. per acre per day, yielding a bright and odorless effluent. It appeared evident, however, on my visit that the applied sewage is of unusual character, being mainly clear wash water from boilers and manufacturing processes with fragments of fecal matter floating in it only here and there. Furthermore, its temperature is raised by the spent steam to 70° and over at times. In the trickling filter house the air was wet and steamy, but without any of the offensive odor of ordinary sewage.

For results of general significance on the applicability of trickling filters we must turn to the Columbus experiments. We are all familiar with the inception of these most important investigations. In the fall of 1903 the city appropriated $1 200 000 for the improvement of its sewerage system and the purification of its sewage, and the authorities were sufficiently farsighted to devote $46 000 of the money to a preliminary study of the methods of disposal best suited to the local conditions. An admirable experiment station was designed and a corps of fourteen experts under the direction of Messrs. Hering and Fuller began work Aug. 16, 1904. It includes a laboratory, one set of open tanks for preliminary treatment and three sets of filters, with a gallery under a frame covering, for each set. (Fig. 10.) The sewage, amounting to some 350 000 gal. per day, is raised by a centrifugal pump to a screen chamber in which it passes through two movable screens of three-eighths-in. diagonal wire mesh. Next it passes to one of the tanks for preliminary treatment. These are seven in number, each 40 ft. by 8 ft. and 8 ft. deep at the upper end and 9 ft. deep at the lower end, built of wood lined with galvanized iron. The first two tanks are called grit chambers, the sewage flowing through in about 1.5 hr., and these tanks are used as a preliminary to all the other processes. The other five tanks are either "plain sedimentation" or septic tanks, in which the sewage remains 8 hr. or more, the difference being that the former are emptied and cleaned whenever septic action begins, while the latter have not so far been cleaned. In the septic tanks periods of 8, 16 and 24 hr. are under comparison.

The sewage after treatment by one of these three preliminary processes (grit chamber, plain sedimentation basin or septic tank) is finally purified by treatment in one or more of thirty-five experimental filters. These are cypress tanks 6 ft. deep; one is 10 ft. in diameter, four 12 ft. 10.75 in. in diameter and thirty 7.5 ft. in diameter. They are all open filters and arranged for the most part in two blocks of two rows each with a covered dosing and sampling gallery between the rows, in which all the engineering details of operation are regulated with the greatest accuracy. Twenty-one are intermittent sand filters, 2 primary and 4 secondary contact beds of broken limestone, 2 coke strainers and 5 trickling filters. With this splendid plant the widest possible series of combinations can be tried, including sand filters, trickling filters and contact beds alone, either of these preceded by plain sedimentation or septic treatment and sand filters preceded by contact or trickling filters.

One of the most striking points about this plant is the considerable amount of solid matter which it has been found necessary to remove. First, the sewage is screened where it is pumped out from the sewer; next it passes through two screens of three-eighths in. mesh in the screen chamber; next it settles for an hour and a half in the grit chambers. All the sewage without exception is purified to this extent before its regular treatment begins. I was told that in the sedimentation tanks 2.5 tons of sludge collected per million gallons of sewage treated, while in the septic tanks only half this amount had accumulated with no surface scum. In the second place I was struck with the marked success of the aërobic processes. Sand filters were operating well at rates well above 500 000 gal.; but the thing that interested me most was to see the trickling filter doing good work under most adverse conditions. These tanks are dosed by a spray from an ingenious sprinkler head designed at the station, and while more than a foot of ice had formed round the edges of the beds the area within reach of the spray was kept free and in good condition by the warmth of the sewage. (Fig. 9.)

The report which we may expect from Mr. G. A. Johnson and his associates at the station sometime next autumn will be awaited with the keenest interest. If, as seems probable, it should recommend one of the newer processes of purification, treatment on trickling beds, for example, it will mark an epoch in American practice. Its greatest significance, however, will lie in the fact that it furnishes a standard for the procedure of other communities in the design of sewage plants. While London and Birmingham and Leeds and Manchester have carried out vast experiments upon this subject, Columbus is the first American municipality to make a careful study of local conditions before the construction of a sewage disposal system. It is to be hoped that in the future this may come to be recognized as the only sensible and economical way to attack the question. There are local conditions which make the treatment of each sewage more or less a special problem. In small plants slight differences may be ignored; but no large city should install a purification system without just such an investigation as that in which Columbus has taken the lead.

Such special studies will not only throw light on purely local problems, but must add to our general knowledge of the underlying principles of sewage disposal. Each case has indeed peculiarities of its own; but certain fundamental laws may be formulated which will materially simplify the solution of the individual problem. Thus we now know that chemical precipitation is only in exceptional cases a satisfactory process for preliminary treatment. There are numerous similar important questions still unanswered. We know that sufficient straining and settling to remove paper and garbage, gravel and silt, is always desirable. After this has been accomplished, is it generally of advantage to remove any portion of the suspended solids by fine strainers or by septic treatment, or can all the organic matter be oxidized without the production of putrescible sludge which more or less attends all anaërobic processes? When American sewage is treated in the septic tank what causes the marked variation in the results obtained? Are periods of septic action of less than twelve hours desirable? For subsequent treatment, what are the comparative merits of the contact and the trickling filter? If the trickling filter be used, what is the cheapest system for securing adequate distribution? With intermittent filters, how rapid a rate can be attained under practical conditions, and by what frequency of dosing? These are some of the general questions which press for settlement and whose solution in one set of experiments will be of value, when corrected for local differences, in every other case.

Besides the study of local conditions and the formulation of general principles of engineering practice, we need a third class of data, of a more theoretical character. The processes of sewage purification are chemical changes carried out, as we now believe, by the activity of the bacteria. Sewage treatment is undertaken in order to remove putrescible organic matter, and its efficiency must be measured by chemical tests which shall record the amount and condition of the carbonaceous and nitrogenous material. We need, therefore, more detailed studies on the methods and the interpretation of chemical analysis. As the end of the process is chemical, and its success is measured by chemical methods, so the agents which carry it out are the bacteria, and the conditions which favor or retard it must be determined by bacteriological investigations. Such researches in pure chemistry and bacteriology as are being carried out at Worcester by Prof. L. P. Kinnicutt, at Lawrence by Messrs. H. W. Clark and S. D. Gage, and at Columbus by Mr. W. R. Copeland, must furnish the data which shall lead to the practical development of the art of sewage purification in the future.

In the sewage of the South Metropolitan District of Boston there is discharged in one year 1 500 000 kg. of nitrogen in the form of free ammonia, and 500 000 kg. more as albuminoid ammonia. To convert such vast amounts of material into an innocuous form is a problem in industrial chemistry, of no mean magnitude. It cannot be solved by rule of thumb methods. Theoretical studies, local investigations, expert construction and intelligent supervision are required satisfactorily to meet it.

REFERENCES.

Alvord, J. W.—

The Practical Operation of Sewage Purification Plants. Milwaukee.

Alvord, J. W. (1902.)

Sewage Purification Plants. Journal of the Western Society of Engineers. VII. 1902, 113.

Marston, A. (1903.)

Sewage Disposal in Iowa. Journal of the Western Society of Engineers. VIII. 1903, 638.

Pratt, R. W. (1904.)

The Columbus Testing Station. Ohio Sanitary Bulletin. IX. 1904, 177.

Pratt, R. W. (1905.)

Report on an Examination of Sewage Purification Plants in Ohio. Eighteenth Annual Report of the State Board of Health for the year 1903.

Shields, W. S. (1904.)

Filters vs. Contact Beds in Sewage Purification. Proceedings of the Indiana Engineering Society. 1904.

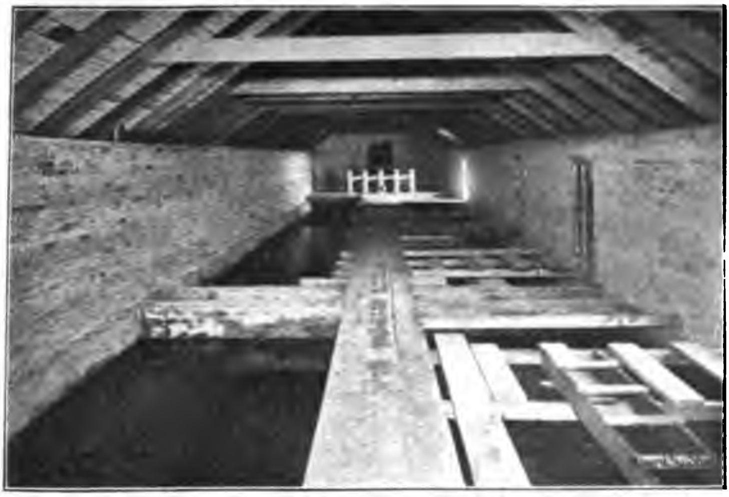
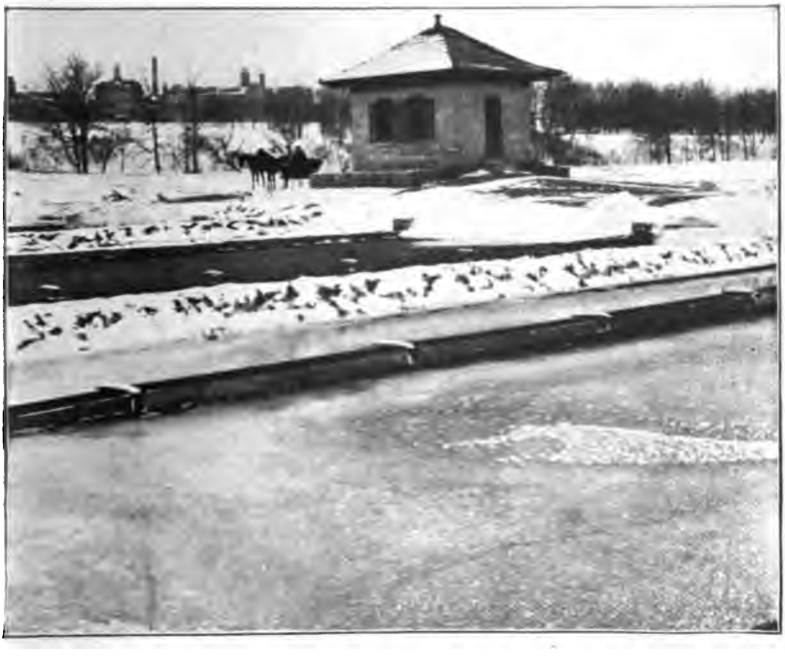


FIG. 1. INTERIOR OF SEPTIC TANK AT LAKE FOREST. IN FOREGROUND LATERAL TROUGH FOR COMBINING VARIOUS COMPARTMENTS. IN BACKGROUND AUTOMATIC DIVERSION CHAMBER. (After Alvord.)



REGULATOR HOUSE, WAUWATOSA COUNTY INSTITUTIONS

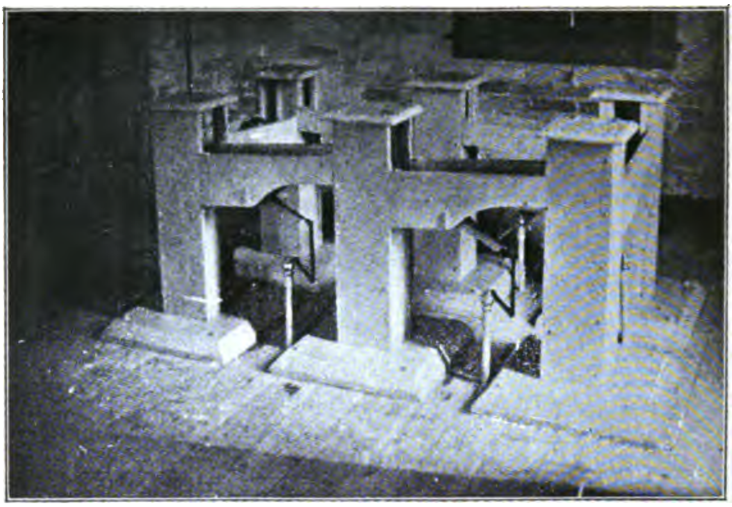


FIG. 3. AUTOMATIC BALL-CONTROLLED DEVICE OPERATING SIX INTERMITTENT FILTRATION BEDS AT WAUWATOSA, WIS. VIEW TAKEN FOUR MINUTES AFTER DISCHARGE IN DIVERSION CHAMBER. DOSE, 6 000 GAL.
(After Alvord)

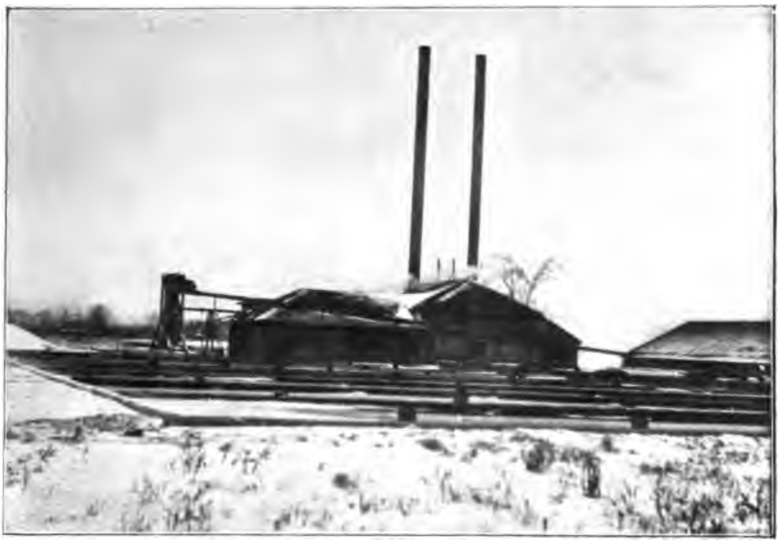


FIG. 5. EAST CLEVELAND PUMPING STATION, WITH RUNWAY FOR SLUDGE FROM WELL, SEPTIC TANK HOUSE (ON RIGHT), AND FILTERS OF STONE WITH AERATING DEVICES.

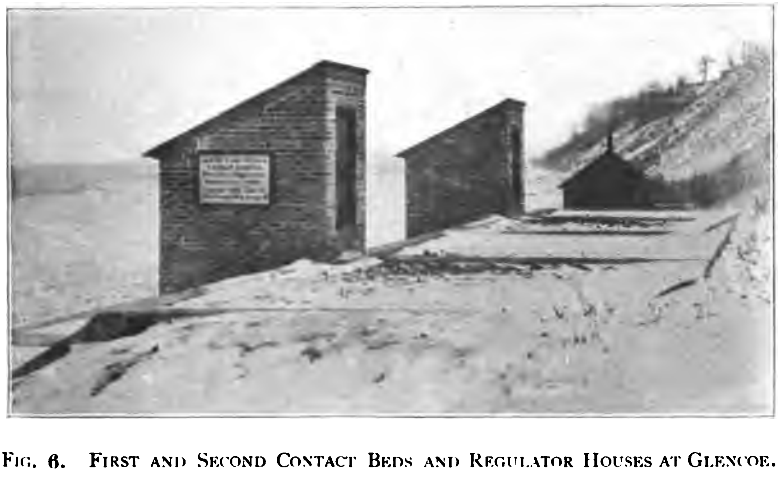


FIG. 6. FIRST AND SECOND CONTACT BEDS AND REGULATOR HOUSES AT GLENCOE.

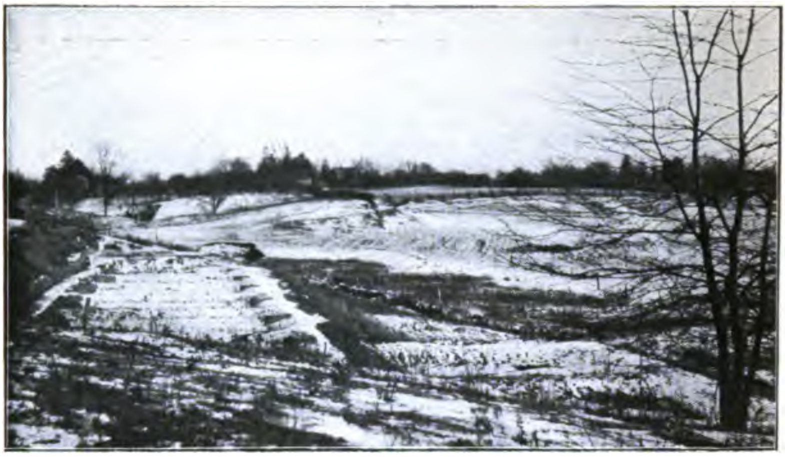


Fig. 7. First and Second Contact Beds, with Septic Tank in Background at Left, at Westerville.

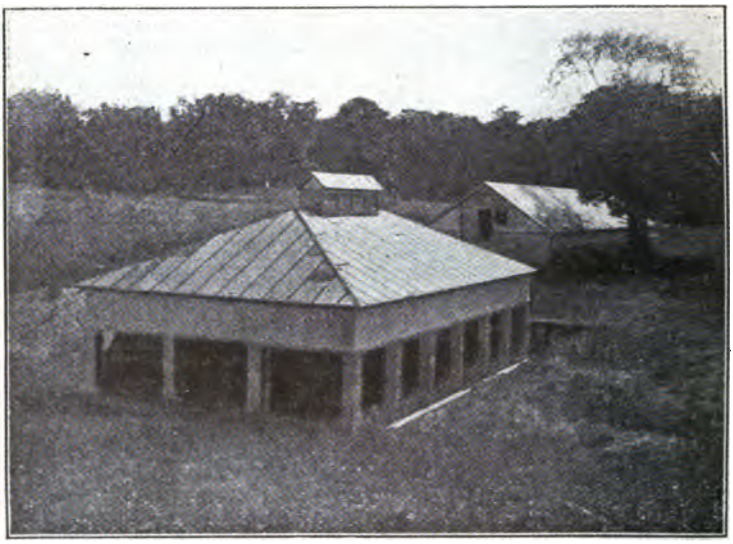


Fig. 8. West Allis Aërobic Filter.
(After Shields.)

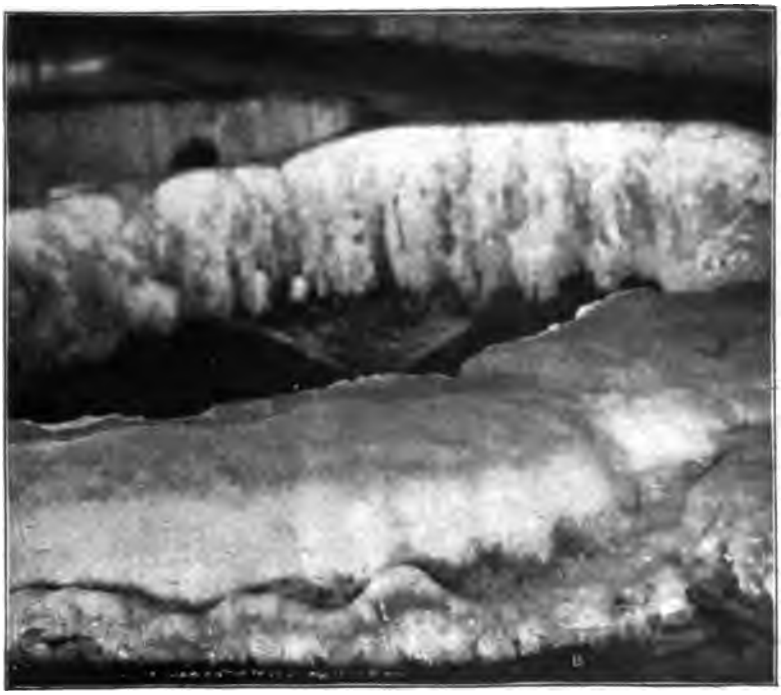


FIG. 9. COLUMBUS TESTING STATION. SPRINKLING FILTER.

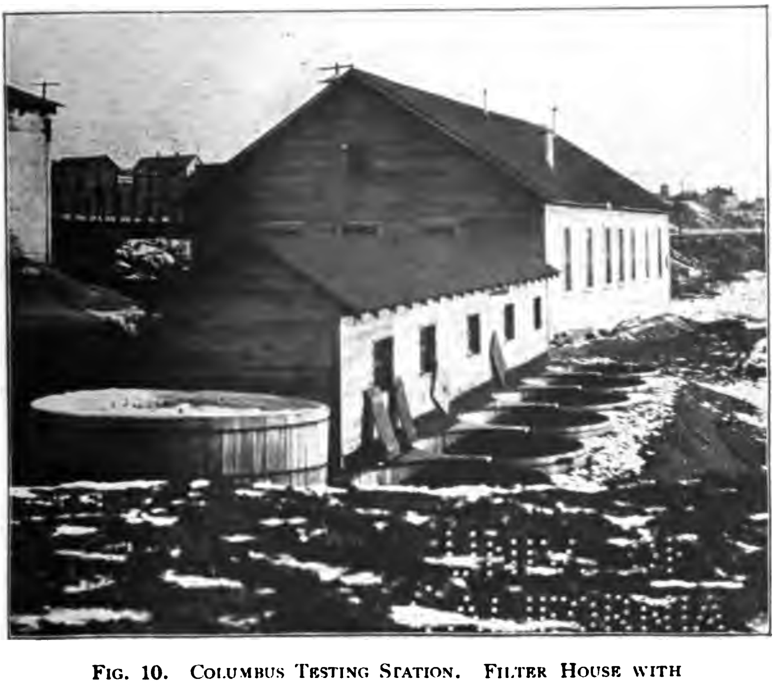


FIG. 10. COLUMBUS TESTING STATION. FILTER HOUSE WITH

ON THE PRESENT RELATIVE RESPONSIBILITY OF PUBLIC WATER SUPPLIES AND OTHER FACTORS FOR THE CAUSATION OF TYPHOID FEVER.

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[*Read November 9, 1905.*]

In a paper read before this Association in 1901, the rise and progress of water-supply sanitation in the nineteenth century was traced with some care. (Sedgwick, 1901.) It was then shown that the responsibility of public water supplies as sources of typhoid fever was first made conspicuous by the epidemics at Lausen, Switzerland, in 1872 (Hägler, 1873), and at Caterham, England, in 1879 (Thorne Thorne, 1880). In this country evidence of the same character was not long lacking; for in 1885 the thriving mining town of Plymouth, Pa., suffered one of the most disastrous water epidemics of which we have even yet any record. (Taylor, 1886.) The great epidemics at Lowell and Lawrence in 1890–91 added new emphasis to the previous lessons (Sedgwick, 1893, *a*); but nevertheless a majority of the largest cities of the United States have continued almost up to the present day to drink water more or less infected with typhoid fever. In the period 1898–1903, there were nineteen cities in the United States of over 200 000 population. Twelve of the nineteen were furnished with public water supplies drawn unpurified from polluted rivers or lakes. The typhoid death-rates in these cities per 100 000 population were as follows (Fuller, Ferguson, and Jeup, 1904):

Pittsburgh	122
Washington	66
Louisville	60
Cleveland	51
Philadelphia	51
Cincinnati	45
Minneapolis	42

Chicago	31
St. Louis	31
Buffalo	29
Detroit	18
Milwaukee	18

For the other seven cities not having supplies drawn from grossly polluted sources, the corresponding rates were as follows:

New Orleans	49
Baltimore	35
San Francisco	31
Boston	26
Jersey City	22
Newark	21
New York	19

There are causes other than the public water supply for the high typhoid death-rates in New Orleans and perhaps in Baltimore. Where no such factors are operative the cities with reasonably pure water supplies exhibit typhoid rates ranging from 20 to 30; 25 would be a fair average figure for American cities of this class. The excess over 25 deaths per 100 000 in the case of Pittsburg, Washington, Louisville, Philadelphia, Cincinnati, and Minneapolis is unquestionably the tax paid by those municipalities for their polluted water supplies. In the first five cities alone this needless waste amounts to 1 200 lives per annum.

And yet great progress has been made in the right direction. The replacement of water derived directly from polluted streams, by filtered or well-stored supplies, goes on with increasing rapidity. Jersey City, for example, where the typhoid death-rate ranged from 52 to 94 between 1890 and 1896, in the latter year abandoned the Passaic River at a point where it was heavily polluted by the sewage of Paterson and Passaic, with the result that the rates for the four years immediately succeeding fell to 21, 36, 15, and 21. Albany effected an equally striking reduction in its typhoid death-rate when a municipal filter was introduced in 1899. (Fuller, Ferguson, and Jeup, 1904.) Of the other communities mentioned above, Washington and Louisville have installed filtration plants within the present year. Philadelphia's system is partially installed, and one of the most serious indictments against the one-time bosses of that apparently redeemed city is the charge that the delay in the completion of this sanitary work is responsible for 1 200 deaths from typhoid fever. Pittsburg and Cincinnati, too, have begun the construction of municipal filter plants, and before many more years the large American city which drinks the unpurified water of a stream, or of a lake with unprotected watershed, will be an exception and an anomaly.

Of special interest in this connection are the statistics of the state of Massachusetts, where the supervision of the public water supplies has been more thoroughly carried out than in any other American commonwealth. In the period 1886–90, the typhoid death-rate for Boston was 39 per 100 000, and for Newton, with an excellent ground-water supply, was 40. The rate for all the cities of the state taken collectively was somewhat higher (46), and the two large cities of Lowell and Lawrence, using the polluted water of the Merrimack River, had each a rate of 112. As later events showed, two-thirds of the typhoid fever in Lowell and Lawrence was caused by water, and this excess, of course, materially raised the rate for the total urban population of the state.

Between 1891 and 1895 the unpurified river-water supplies of Lowell and Lawrence were abandoned, and for the period 1896–1900 their rates fell to 25 and 24 respectively. In at least one of these communities, Lowell, the present water supply, from a series of driven wells, is absolutely protected from infection. In Newton with a rate of 20 and in Woburn with a rate of 13, the conditions are similar. Gloucester, Pittsfield, and North Adams, with rates of 16, 25, and 39 respectively, possess surface supplies of unexceptionable quality from uninhabited watersheds, probably as free from pollution as such waters can often be.

The North Adams typhoid rate may be regarded as due to certain exceptional conditions. We may, however, consider the other five communities as typical of most of the cities of the state, differing only in the fact that our knowledge of the purity of their water supplies is more certain than in other cases. In these five cities we find typhoid rates of 13, 16, 20, 25, and 25. We are confident that these rates are not raised by pollution of the public water supplies and that the influence of private well water upon them is negligible. It therefore follows that typhoid deaths ranging from 15 to 25 per 100 000 are due in these cities to causes other than polluted water; and it is probably fair to assume that at present in similar American communities about this amount of typhoid fever may be expected to occur without its intervention. When we find that the typhoid rate for the whole of Massachusetts in 1896–1900 was only 24, in 1901 only 19, and in 1902 only 22, it seems evident that in this state at least public water supplies are not factors of paramount importance. Eternal vigilance is, of course, the only price of freedom from water-borne typhoid. Particularly in the case of unfiltered surface supplies, such as are common in New England, danger must always be recognized as possible. The 450 cases of typhoid fever at New Haven in 1901 (Smith, 1902) were caused by temporary pollution on a watershed quite as good as that of many a supply in Massachusetts. So great is the danger of such a mishap that as the country becomes more densely populated it must eventually be recognized that no surface water is safe for drinking without purification. Even with filtered supplies only careful and constant supervision will insure safety. Witness the 1 270 cases of typhoid fever at Butler, Pa., in 1903, due to almost criminal carelessness in the operation of the filter plant of the local water company. (Soper, 1903.) The responsibility which rests upon water-works officials still remains, and must always remain, heavy; but, broadly speaking, when this responsibility is well discharged, we may say with confidence, in the light of the expert knowledge at our disposal, that public water supplies play an insignificant part in the causation of typhoid fever in New England.

It must also be remembered that our requirements as to the purity of our supplies have all along been steadily rising and that a far higher degree of purity is to-day demanded, and rightly demanded, in water supplies than was formerly expected or possible. The extraordinary demonstration furnished by the experience of the city of Lawrence with filtered water, in which it has been shown by Mr. Hiram F. Mills and by Hazen (Hazen, 1905) that the general death-rate has been reduced much more than the typhoid death-rate, can only mean that the germs of other common diseases besides typhoid fever are carried by water, unless, indeed, it turns out in the future, as is possible, that the vital resistance of the people using the water has been increased, as the purity of the water has risen. Either alternative is extremely suggestive for water-works officials, and opens out inviting fields for investigation and research.

With the progress of sanitary reform the relative responsibility of water for typhoid fever necessarily decreases. As recently as 1902, Mr. M. N. Baker wrote, "Not only is typhoid one of the leading causes of death in America, but the greater part of it is conveyed, directly or indirectly, through water." (Baker, 1902.) This is still true in Philadelphia and Pittsburg, but it is not true to day, as we have seen, in Massachusetts. Meanwhile, year by year the relative importance of what we may call the *residual typhoid* becomes greater. It is increasingly necessary that the attention of sanitarians should be directed to that tax of 15 to 25 deaths (which means 150–250 cases) per 100 000 population, which typhoid fever still levies on communities provided with ever so pure a water supply. To what shall we attribute this residuum of the disease, so constantly present in most American cities?

In attacking this problem, which concerns not only the epidemiologist but also the practical water-works official who desires to know just how far the water supply under his care may justly come under suspicion, we must begin by remembering that the extension of an infectious disease is the spread of a microscopic parasite; and that this follows much the same course as the distribution of any higher plant. Wheat comes from the ear and eventually finds its way to a favorable soil where it may sprout. So the seed of typhoid infection originates in the body of the typhoid patient and germinates in the intestinal canal of a susceptible victim. The intermediate steps in the history of the wheat may be various. The wind, or a bird, the hairy coat of an animal, or the hand of man, may carry the grain from the place of its origin to the new soil where it sprouts and multiplies. Equally diverse may be the paths by which the typhoid germ is propagated from person to person. Air, earth, water, milk, fruit, flies, soiled clothing, human beings, may intervene; or the transfer may be so direct as to require no intermediary save the two individuals chiefly concerned.

The more we study the prevalence of typhoid fever, the more it becomes evident that its spread goes on in two ways. The first is that in which infection is distributed by a single common medium to a large number of persons at one time. This is characterized by the sickening simultaneously, or at least within a period of a fortnight, of a number of persons who have, perhaps, partaken of some common article of food. Such an explosive outbreak is what the public generally means by an epidemic. Sometimes, on the other hand, we find an undue prevalence of typhoid fever without such coincidence in time and, therefore, of exciting cause. An excessive number of cases of the disease occur which cannot be connected by any common epidemiological bond, but follow each other in a slow succession of scattered or sporadic cases, or in that closer association as to locality to which the older sanitarians applied the word "endemic." As this word is outworn, because by custom associated with the idea of some mysterious but wholly intangible quality inherent in a definite soil or region, the term *prosodemic* has been suggested by one of us for this form of disease "which progresses gradually from person to person by routes which, whether direct or indirect, are often different for each individual case," the term *epidemic* being restricted to "that special case in which circumstances permit the transfer of infection to a large number of persons through the same medium, and at approximately the same time" (Winslow, 1901).

True epidemic typhoid, in the sense in which we have thus defined the word, is generally easy to trace back to its exciting cause. The coincidence of cases fixes the date of infection with approximate accuracy, and the scope of inquiry is at once narrowed down to those vehicles of infection to which all the sufferers have been jointly exposed. Furthermore there are comparatively few methods by which typhoid infection is likely to be transmitted to a large number of persons at the same time. The vast majority of recorded epidemics have been traced with reasonable certainty to one of three vehicles, water, milk, or shellfish. Of these water is by far the most important.

The residual typhoid which still afflicts American cities and large towns, even after they have acquired good water supplies, is undoubtedly due partly to occasional epidemics in which the vehicle is some material other than water,—such as small milk epidemics, shellfish epidemics, celery epidemics, and the like,—even where outbreaks of notable size, in which the infection of a large number of persons can be traced to a common source, are absent. Outbreaks due to milk, although considerable, account, however, for but an insignificant proportion of the total and constant annual mortality; and epidemics distinctly traced to shellfish and raw vegetables have been still more exceptional.

Most of the typhoid cases which occur to-day in Massachusetts and in other communities provided with reasonably good water supplies, are of the sort we have designated as "prosodemic." They are transmitted from person to person by routes which differ in individual cases. The methods by which inspection spreads are almost infinite in number. The chain begins with excreta and ends usually with food; but the intermediate links may be few or many. The fingers of unprofessional attendants upon typhoid patients, or of the patients themselves during the early stages of the disease, and flies, which so often pass freely from infected privies to adjacent larders, suggest themselves as ready vehicles. Sometimes the route is so direct that typhoid fever, under uncleanly conditions, becomes for all practical purposes a contagious disease. Sometimes it is so roundabout as to baffle any attempt to trace it.

The devious and obscure course of prosodemic typhoid is no new discovery. It has never been shown more clearly than by Dr. William Budd in his famous monograph published in 1873. (Budd, 1873.) The little village of North Tawton in England suffered a severe outbreak of this character in 1839, over eighty cases occurring between June and November of that year, following each other slowly, several members of a family taking the disease in almost every house in which it appeared. Three infected persons left the place during this summer, and each one formed a new focus for the spread of fever in a region hitherto free from it. In the first case the two children of the sufferer succumbed to the infection; in the second case a friend who acted as nurse took the disease and in turn transmitted it to his two children and his brother; the third of the visitors left North Tawton to stay with a brother at another hamlet seven miles away; the brother's wife, the brother himself, two farm hands, a friend who had come to take charge of the house, another farm hand, two servants, and the daughter of the original visitor successively developed typhoid fever. Evidence of the direct transmission of the disease could scarcely be more conclusive.

In this country the outbreak at Bondsville, Mass., where one hundred cases occurred among the mill operatives in the summer of 1892 (Sedgwick, 1893, *b*), and that of Newport, R. I., in 1900, in which some forty cases, apparently caused by an infected well, were followed by double that number of secondary cases (Winslow, 1901), furnish more recent examples of the same phenomena. In each of these instances the slow succession of cases and the bond of physical association between the victims gave evidence of the prosodemic character of the disease.

There can be little doubt that the emphasis on water and milk epidemics, which produce a striking effect upon the public mind from the number and coincidence of the resulting cases, has led to a general neglect of the less obvious but equally grave danger involved in the spread of prosodemic typhoid. Even the well-water theory may be overworked, for long ago Dr. Rolleston remarked: "And I would add that certain observations which I made recently in a fever-stricken village . . . have induced me to think that of the two recognized foci for infection [in typhoid fever], the bespattered privy and the contaminated well, the former may be the one which is more commonly at work." (Rolleston, 1869.) The doctrine that typhoid fever is "infectious but not contagious" has slain its thousands. In dirty surroundings, typhoid is essentially a contagious disease. Even among trained attendants, with all the advantages of a hospital environment, the number of secondary cases of typhoid is considerable. Collie has recorded that one hundred cases occurred in the staff of the Asylum Board Hospitals of London from 1892 to 1899. (Collie, 1904.)

In the unsanitary conditions which, to our national disgrace, prevailed in the camps of our volunteer soldiery during the Spanish War, the conditions favorable to the transmission of disease reached a maximum and furnished a striking object lesson in the transmission of prosodemic typhoid. (Reed, Vaughan, and Shakespeare, 1904.) Of 107 973 officers and men in the national encampments during the year 1898, 20 738, or nearly one-fifth, developed typhoid fever, with 1 580 deaths.

The disease was spread in a series of independent company outbreaks affecting over 90 per cent. of the volunteer regiments within eight weeks of their assembly in camp. Infected water played no important part. Flies undoubtedly served as carriers of infection, and it was believed that the virus was disseminated to some extent in the form of dust. The vast majority of the cases, however, were caused by more or less direct transfer of infected material under unsanitary conditions. Of 1 608 cases which were studied in detail, 62 per cent. were definitely connected in place and time with earlier cases. The chief factor controlling the incidence of the disease was the system used for the disposal of excreta. Thus, in the Seventh Army Corps, the First Division, with a water-carriage system, had 1 030 cases of typhoid fever; the Third Division, with regulation pits for disposal, had 1 292 cases; the Second, with the thoroughly unsanitary "tub" system, had 2 693 cases. This history of typhoid in the army is simply the history, on an intensive scale, of all prosodemic typhoid.

One of the most interesting features of the "residual typhoid" (not due to polluted water supplies) is its definite seasonal prevalence. In communities provided with reasonably pure water supplies, the typhoid, or as it was called by the older sanitarians, the "fall fever," follows the curve of seasonal temperature with extraordinary regularity. If the monthly deaths from the disease be plotted and compared with the monthly temperature it will be found that the curves are almost parallel, the typhoid fever rising with the temperature after about two months, an interval representing the incubation period of disease and the time which elapses before death. Where the temperature curve is acute, that of the mortality follows it, whereas in a mild climate, the distribution of the disease is more even. In the southern hemisphere both curves are reversed. We have elsewhere shown that these phenomena are so constant and so universal as to suggest in the strongest manner a direct relation between temperature and typhoid fever; and our theory of this relation is as follows:

"The bacteriology and the etiology of typhoid fever both indicate that its causal agents cannot be abundant in the environment during the colder seasons of the year. The germs of the disease are carried over the winter in the bodies of a few patients and, perhaps, in vaults or other deposits of organic matter where they are protected from the severity of the season. The number of persons who receive infection from the discharge of these winter cases will depend, other things being equal, upon the length of time for which the bacteria cast in the discharges into the environment remain alive and virulent. The length of the period during which the microbes live will depend largely upon the general temperature; as the season grows milder, more and more of each crop of germs sent at random into the outer world will survive long enough to gain entry into a human being and bear fruit. The process will be cumulative. Each case will cause more secondary cases; and each of the latter will have a still more extensive opportunity for widespread damage. In our opinion the most reasonable explanation of the seasonal variations of typhoid fever is a direct effect of temperature upon the persistence in nature of germs which proceed from previous victims of the disease." (Sedgwick and Winslow, 1902.)

In cities having polluted water supplies there was an interesting departure from the normal seasonal distribution of typhoid. We found the normal maximum in September or October; but in some cases there were also secondary maxima in the fall and spring as shown in the curves for Chicago. These high death-rates in the cooler months were at first puzzling, and such instances have obscured the usual seasonal variations and led some sanitarians to deny the existence of any relation between typhoid fever and temperature. As soon, however, as it appeared that curves of this type were associated with polluted water supplies, their significance became clear. The fall and spring epidemics coincide with the fall rains and the spring thaws, which wash infecting material from vaults on the banks, or through storm overflows, into the water supplies, carrying it fresh and virulent to the consumers below. A seasonal distribution of this sort appears to be characteristic of many communities drinking from unprotected surface waters; and it was found by us in this country in Chicago, Cincinnati, Newark, and Philadelphia. On the other hand the large majority of cities, including Atlanta, Baltimore, Boston, Charleston, Denver, Mobile, Montreal, New Orleans, New York, St. Paul, San Francisco, and the District of Columbia showed a close and constant relation between the temperature and the seasonal prevalence of typhoid fever.

It is obvious that the difficulties of tracing the path by which prosodemic typhoid spreads in the individual case must often be insuperable. In a crowded community there are so many possible modes of transfer in each separate instance that it is generally impossible to demonstrate the chain of infection, as may often be done in an epidemic inflicted on a number of persons at a definite time and by a single common cause. As intermediate vehicles of the disease, we may have soiled clothing, or bedding, or the woodwork of privies, water, milk, celery, lettuce, or fruit. Food, fingers, and flies offer an alliterative summary of the most common agents. The one thing upon which we can fix our attention with certainty is the common point of departure. Every germ of typhoid fever, whatever its subsequent history, originates in the body of a typhoid patient and leaves it in the excreta. Every case of typhoid fever is due to the presence of excreta on food or fingers, or in some other place where excreta should not be. Filth is the fundamental condition for the spread of typhoid fever; cleanliness the universal panacea for its eradication.

Exactly how much responsibility ought to be assigned to each of the individual factors it is not always possible to say, and we need, therefore, to be particularly careful not to jump too hastily to conclusions. As regards flies, for example, we must remember that while these are unquestionably important vehicles in the spread of typhoid fever, the striking fact remains that the time of greatest mortality from typhoid fever in Massachusetts is not such as to justify, offhand, a belief that flies are the principal vehicle of that disease in this state; for, while typhoid mortality reaches its maximum about the middle of September, a fact which demonstrates that the germs are received by the inhabitants in greatest numbers or under most favorable conditions at some time in August, it is generally believed that September is often, if not always, the worst month of flies. On the other hand, the truth may be, of course, that even if flies are more *numerous* in September they are less *active* than in August, and we must therefore be careful not to dogmatize on either side without sufficient evidence. One fact which stands out with especial clearness the longer we study the subject is that in spite of all that may be, and has been, said to the contrary, *typhoid fever is a contagious disease.* Instead of saying, as is often said, that "typhoid fever is infectious, not contagious," we need to say to-day that "typhoid fever is both infectious and contagious"; and, doubtless, it is in part for this very reason that it has been found so difficult to exterminate.

The conclusion of the whole matter is perfectly clear. Dirt and disease go generally hand in hand, and the importance of disinfection as near as possible to the source of discharge becomes more and more obvious every day. It is plainly wasteful as well as dangerous to allow disease germs to escape from their original sources of supply and become distributed in the environment. Extraordinary pains are therefore requisite in order to destroy their dragon's brood at the very outset, and we cannot help feeling that boards of health are here often remiss. Too often boards of health content themselves with routine work; too often they are more careful for their own political lives than for the lives of the people whom they serve. What we greatly need at present in many of our cities and towns is greater *activity* and *aggressiveness* on the parts of boards of health, especially in respect to sanitation as opposed to hygiene, so that disinfection shall be more carefully done, so that polluted wells, which are still frequently in evidence in many of our thriving towns and cities, shall be closed up, and so that privy vaults and other primitive methods of disposal of excreta which are unfortunately too characteristic of American cities and towns, and whose disappearance is a sure index of effective civilization, shall be cleaned up and done away. Meantime, all good citizens should uphold boards of health in all their reasonable activities, and contribute as far as they can towards that enlightened public spirit which shall insist upon a higher standard of cleanliness in all our cities and towns. But even all these things are not enough.

We greatly need an extension of power in our state sanitary authorities so that these shall be not merely advisory and judicial, but shall have, besides the power and duty of investigating and reporting, some measure of *control,* so that when local authorities are neglectful or powerless, a higher authority may step in and protect the lives and health of the people; for local carelessness, neglect, or ignorance may, and often do, entail the widespread injury of states and even nations. In Massachusetts, for example, we ought to have some system of district sanitary or public health inspectors, and some system of centralized authority similar to that which we have in the state medical examiner system, a system which has replaced with so much advantage the antiquated "coroner" system of former days.

This is an old story. Yet as long as conditions remain unimproved it is a story which must again and again be repeated. The authors of this paper presented a communication bearing a similar title before the American Public Health Association at its New Orleans meeting in 1902, with the following conclusions (Sedgwick and Winslow, 1903) : *First*, that in the state of Massachusetts and in some of the larger cities of the United States the public water supplies are now relatively unimportant as vehicles of typhoid fever.

Second, that in cities having pure water supplies the annual curve of typhoid fever mortality closely follows that of annual temperature.

Third, that in urban communities supplied with pure water there still remains a typhoid fever tax of from 15 to 25 deaths per 100 000 population. (To this we now give the name *residual typhoid.*)

Fourth, that this tax is due, not to any peculiar condition of soil, locality, or climate ("endemic" factors), but to incomplete disinfection of typhoid excreta, with subsequent infection of various articles of food and drink. These factors, when acting upon a few or many persons at one time, may cause obvious epidemics, sometimes large, though generally small; but more often the infection in moving from one point to another follows various, and often obscure, routes for different victims, and hence may be described as *prosodemic.*

Fifth, that the only remedies for such prosodemic typhoid are absolutely thorough and universal cleanliness, and especially a thorough disinfection of all excreta.

The same conclusions may serve for the present communication, and we propose to reiterate and proclaim them at convenient intervals until the public is aroused and educated to that cleanliness which is next to godliness, and our national excess of typhoid fever ceases to be a discredit to American civilization.

REFERENCES.

Baker, M. N., 1902: Municipal Engineering and Sanitation. New York, 1902.

Budd, W., 1873: Typhoid Fever. London, 1873.

Collie, A., 1904: Infectivity of Enteric Fever. Bristol, 1904.

Fuller, G. W., Ferguson, C. E., and Jeup, B. J. T., 1904; Report upon the Water Supply and Sanitary Conditions of the City of Indianapolis. Indianapolis, 1904.

Hägler, A., 1873: Beiträge zur Enstehungsgeschichte des Typhus und zur Trinkwasserlehre. Deutsches Archiv für klinisches Medizin, XI, 31.

Hazen, A., 1905: Purification of Water for Domestic Use—American Practice. Transactions of the American Society of Civil Engineers, LIV, Part D, 131.

Newark, 1901: Annnal Report of the Department of Health of Newark, N. J., for 1900.

Reed, W., Vaughan, V. C., and Shakespeare, E. O., 1904: Report on the Origin and Spread of Typhoid Fever in United States Military Camps during the Spanish War of 1898. Washington, 1904.

Rolleston, G., 1869: The Earth Closet System. Lancet, XCIV, 319.

Sedgwick, W. T , 1893, *a*: On Epidemics of Typhoid Fever in the Cities of Lowell and Lawrence, with Observations upon Its Existence in Other Cities of the Merrimack Valley, especially in Newburyport. Twenty-fourth Annual Report of the State Board of Health of Massachusetts for 1892, 667.

Sedgwick, 1893, *b*: On Epidemics of Typhoid Fever in the Villages of Bondsville, Provincetown, and Millville, Apparently Due to Secondary Infection. Twenty-fourth Annual Report of the State Board of Health of Massachusetts for 1892, 732.

Sedgwick, W. T., 1901: On the Rise and Progress of Water-Supply Sanitation in the Nineteenth Century. Journal of the New England Water Works Association, XV, 315.

Sedgwick, W. T., and Winslow, C.-E. A., 1902: Statistical Studies on the Seasonal Prevalence of Typhoid Fever in Various Countries and Its Relation to Seasonal Temperature. Memoirs of the American Adademy of Arts and Sciences, XII, 521.

Sedgwick, W. T., and Winslow, C.-E. A., 1903: On the Relative Importance of Public Water Supplies and Other Factors in the Causation of Typhoid Fever. Transactions of the American Public Health Association, XXVIII, New Orleans meeting, 288.

Smith, H. E., 1902: Report on the Epidemic of Typhoid Fever in New Haven during the Spring of 1901. Twenty-fourth Annual Report of the State Board of Health of Connecticut for 1901, 280.

Soper, G. A., 1903: The Typhoid Epidemic at Butler, Pa. Engineering News, L, 574.

Taylor, L. H., 1896: Report upon the Epidemic of Typhoid Fever at Plymouth, Pa. First Annual Report of the State Board of Health of Pennsylvania for 1885, 176.

Thorne, Thorne R., 1880: On an Extensive Epidemic of Enteric Fever at Red Hill, Caterham, and Other Adjoining Places. Supplement to the Ninth Annual Report of the Local Government Board containing the Report of the Medical Officer for 1879, 78.

Winslow, C.-E. A., 1901: Typhoid Fever at Newport, R. I., in 1900 and Its Relation to Defective Sanitation. Technology Quarterly, XIV, 110.

THE TOXIC EFFECT OF CERTAIN ACIDS UPON TYPHOID AND COLON BACILLI IN RELATION TO THE DEGREE OF THEIR DISSOCIATION.*

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1. INTRODUCTION.

THE researches of the physical chemists, under the leadership of Arrhenius and Nernst, have shown that certain substances in aqueous solution become dissociated or broken up into electrically charged part-molecules (atoms or groups of atoms), which are called ions. The extent to which this occurs varies with different substances and is greatest in the most dilute solutions. With strong acids and bases, and their salts, it is practically complete at a strength of 0.001 normal. With such solutions it is evident that any effect, chemical or physiological, which they exert, must be due to the dissociated ions. The properties of a dilute solution of sodium chloride are the properties of sodium and chlorine ions, and the properties of hydrochloric acid, of hydrogen and chlorine ions. By the comparison of a series of properly selected compounds it is easy to determine the specific influence of each ion. The study of the toxic action of various substances in the light of these facts promises to be of great assistance in the development of a rational theory of disinfection.

The first definite statement of the relation between dissociation and disinfectant power with which we are familiar was made by Dreser. This author (Dreser, 1893), in a study of the pharmacological value of various salts of mercury, found that the double hyposulphite of mercury and potassium was much less poisonous than other compounds containing the same amount of mercury, and explained the phenomenon by the fact that this salt on dissociation does not set free mercury ions, but breaks up into potassium at the cathode and Hg S_4O_6 at the anode. His experiments were made on yeast cells, frogs, and fishes. In the former case he found it possible to prevent all development in a yeast culture by mercury salts, and

* Received for publication March 5, 1906.

then by the addition of potassium hyposulphite to permit fermentation without precipitating any of the mercury, simply by the formation of the differently dissociated double salt.

Scheurlen and Spiro (1897) confirmed the conclusions of Dreser as to the correlation between dissociation and disinfectant action among the mercury salts, and extended them to cover certain compounds of iron. At the same time they maintained that in other cases (the ethylchlorid and ethylsulphate of mercury) strong disinfectant action was apparently due, not to free ions, but to the undissociated molecule.

A number of phenomena which had long been empirically familiar in bacteriology found an easy explanation on the electrolytic theory of disinfection. The effect of temperature in increasing the activity of disinfectants, for example, had been pointed out by Koch (1881), and later by Behring (1890) and Heider (1892), and many others. It was at once obvious that this might be due in some cases to the increased dissociation at high temperatures. It would be well worth while today to see how far the increased activity of disinfectant runs quantitatively parallel to its dissociation. Again, Minervini (1898), and other investigators, have shown that various antiseptic agents (carbolic acid, chromic acid, mercuric chloride, and silver nitrate in Minervini's experiments) are much less active in alcoholic than in aqueous solutions. This fact, too, is easily explicable as due to the diminished dissociation in such solvents.

The relation between dissociation and toxicity was put upon a sound quantitative basis by the work of Krönig and Paul, first published in 1896 (Paul and Krönig, 1896), and in fuller detail in the next year (Krönig and Paul, 1897). These authors carried out an elaborate series of experiments on the disinfectant action of various salts, bases, and acids in the light of the new conclusions of physical chemistry. The details of the investigation were arranged with the greatest care in order to secure comparable results. Spores of *Bacillus anthracis* and vegetative cells of *Micrococcus aureus* were used, dried on Bohemian garnets. By using a definite number of garnets of a certain size shaken up with a suspension of an agar culture, after filtering through paper, and carefully drying, it was found possible to expose approximately the same number of cells in each experiment, The garnets were dried for 12 hours at 7° and exposed in platinum sieves to the action of the disinfectant solution studied. The temperature was kept constant at 18° C. during the experiment, and after the desired time had elapsed the excess of disinfectant was carefully removed by appropriate reagents (neutralization of acids and bases, precipitation of heavy metals with ammonium sulphide, etc.). After thorough rinsing, the garnets were shaken up with water to detach the cells, which were then plated on agar. No attempt was made accurately to fix a killing point by testing a long series of dilutions of each disinfectant, and no exact calculations were made of dissociation. In a general way, however, the number of spores of *B. anthracis* which developed after treatment for a given time varied inversely with the amount of dissociation. Thus in the study of metallic salts it appeared that the activity of various compounds of mercury, silver, copper, and gold was greatest in those actively dissociated, and decreased in those which yield less free metallic ions. Solutions of mercuric chloride and silver nitrate, in alcohol, where no dissociation occurs, showed almost no disinfectant action. Furthermore, the toxic action of a salt having poisonous metallic ions was markedly diminished by the presence of a non-toxic salt of the same acid. This is in accord with physico-chemical theory; in any solution the ratio between the undissociated molecules and the product of free anions and cations is constant, so that the addition of sodium chloride to mercuric chloride keeps the proportion of chlorine ions the same, but replaces a portion of the mercury ions by those of sodium. So it appeared in Krönig and Paul's work that successive additions of sodium chloride to mercuric chloride progressively increased the number of colonies developing after the usual treatment. In the study of different salts of the same metal it was found that the acid radical may also exercise considerable influence on the disinfecting power.

With bases Krönig and Paul found the same general relation to hold, ammonium hydroxid, which is weakly dissociated, being a much less active disinfectant than the corresponding compounds of potassium, sodium, and lithium. The authors noted in a general way a diminution of disinfectant action in the presence of organic compounds. The decrease was most marked with the halogens and oxidizing agents, and less with acids and bases. Disinfectants themselves of organic nature were least affected.

The particular phase of the subject with which we are especially concerned, the disinfectant action of the acids, was not exhaustively treated in this investigation. One series of experiments was made with normal and half-normal solutions, in which it was found that hydrofluoric, nitric, and trichloracetic acids in normal strength killed all the anthrax spores in 120 minutes. Normal chloric, hydrobromic, and hydrochloric acids and half-normal oxalic acid left a few spores alive after eight hours. Normal sulphuric acid was a little less effective, and normal phosphoric, formic, and acetic acids left large numbers of organisms alive after eight hours. Hydrocyanic acid in normal strength showed little action even after 30 hours. The investigators conclude that there is a general relation between the action of the acids and the amount of dissociated hydrogen present; but there appear many exceptions to a strict parallelism. The authors attribute these exceptional effects to the anion or the undissociated molecule, and point out that in more dilute solutions they tend to disappear. Thus, 0.06 normal solutions of hydrochloric, chloric, nitric, and trichloracetic acids showed about the same disinfectant action, apparently due to the presence of an approximately equal amount of dissociated hydrogen.

At a still earlier period a somewhat similar series of investigations to those of Paul and Krönig had been carried out in another field. This was a study of the relation between toxicity and dissociation as measured by the effect of various salts and bases, and a long series of organic and inorganic acids, on the higher plants, by Kahlenberg and True (1896). Their method consisted in determining the maximum strength of solution in which seedlings of *Lupinus albus* could grow. The seedlings were exposed for 15 to 24 hours, and their condition determined by their general appearance and by the growth which had taken place. These plants proved very sensitive to the action of dilute acid, a strength of from 0.00008 to 0.00064 normal killing them in almost every case. It is interesting to note that boric acid was endured in 10 times this strength. In general, the poisonous action ran parallel with the degree of dissociation, but certain of the organic acids showed relations of their own. The authors concluded that "in the case of plants the toxic action of solutions of electrolytes, when dissociation is practically complete, is due to the action of the ions present. When dissociation is not complete, the undissociated part of the electrolyte may also exert a toxic effect." Heald (1896) extended the work of Kahlenberg and True to the seedlings of three other flowering plants, and reached the same general conclusions. All these authors pointed out clearly that the effect of the common mineral acids is due to hydrogen alone, since their anions have almost no strong toxic action when neutral salts are used.

The next work along these general lines was carried out in another field of botany by Stevens (1898), at the University of Chicago, the measure of viability used being the germination of fungus spores. A study had been made by Wüthrich (1892), at a much earlier date on the toxicity of metallic salts and acids for the spores of fungi; and Maillard (1898 and 1899) at about the same time reported experiments on the inhibition of the growth of *Penicillium* by copper salts. In Stevens' experiments the spores were inoculated into hanging-drop preparations of the solutions tested, and examined for development after 24 hours. The five organisms used exhibited marked differences in their susceptibility, although all were much less affected than the phanerogamous seedlings, requiring a strength of 0.01–0.02 normal acid to inhibit germination. The relative toxic effect of various substances was not unlike that observed by Heald and Kahlenberg and True. Mercuric chlorid and various copper salts proved most fatal, the acids and cyanides being less active. By the comparison of various substances it appeared that of the anions, CN, CrO_4, Cr_2O_7, and OH are poisonous, and of the cations, Hg, Cu, and H, while the halogens and SO_4 in dilute solutions exert no influence.

A still more exhaustive study of the effect of toxic agents upon the fungi was made by Clark in the next year (Clark, 1899). This investigator followed the same general method as that of Stevens, exposing spores in hanging-drop cultures to the activity of the agents to be tested. The cultures were divided into four classes: those which grew normally, those which showed irregular or retarded growth, those which failed to develop in the medium tested, but grew after transfer to fresh beef infusion, and those which entirely succumbed to the action of the toxic substances. The wide difference between the concentration of acid producing, respectively, injury, inhibition, and death was one of the most interesting results of these experiments. As in Stevens' work, it was apparent that the fungi are extremely resistant to disinfectants, and it was necessary to use somewhat concentrated solutions, from 0.008 to 0.287 normal acid, for killing. It is perhaps partly for this reason that, as the author says, "in this study no new evidence has been adduced supporting the theory that the chemical activities of a substance are due wholly or chiefly to the ionized portion." On the other hand, it was held that "in the case of several acids, ionization lessens the chemical activities toward the substances involved in the life-processes of the plant." This conclusion is based on calculations of the specific toxicity of each ion and molecule, obtained by comparing the effects of different compounds varying from each other in one element or group. Thus, hydrochloric acid in the solutions used was over 90 per cent. dissociated and since experiments with the similarly dissociated chloride of potassium showed this salt to be practically non-toxic, it is evident that its action was due to the combined effect of the hydrogen ion and the undissociated molecule. Nitric acid, dissociated in the same proportion was much more toxic. Since hydrogen ions are equal in the two cases and since the NO_3 ion is harmless, as shown by experiments with neutral salts, the increased effect must be due to the undissociated part of the molecule of nitric acid. Clark calculates that the toxic value of one molecule of undissociated HNO_3 is 7.7 times that of an ion of hydrogen, so that the acid actually loses nearly seven-eighths of its disinfectant power by becoming ionized.

The effect of sulphuric acid was about the same as that of hydrochloric; since it is less dissociated, the author attributes an appreciable influence to the anion, HSO_4. Acetic acid, at the strength used, is only 2 per cent. dissociated, so that its high toxic effect is due to the un-ionized molecule.

The results obtained in this series of experiments with hydrocyanic acid are also interesting. Krönig and Paul (1897) found this acid almost without effect on anthrax spores, while Kahlenberg and True (1896), on the other hand, record very strong toxic action on the seedlings of higher plants. In Clark's experiments it proved far more fatal than any other acid, being 70 times as active as hydrochloric. The molecule at the concentrations used is probably only slightly dissociated.

In some ways the most important work upon this subject was the very careful study made by Bial, of the antiseptic action of the hydrogen ion of dilute acids upon yeast. He first became interested in the problem from a consideration of the causes which allow production of gas in the stomach, and carried out his earliest experiments by observing the gas formation in yeast cultures in the presence of various substances present in the normal gastric juice. This series of studies (Bial, 1897) showed that the presence of albuminoid substances or of sodium chloride effected a marked restriction of the antiseptic action of hydrochloric acid. Bial at this time did not apply physico-chemical theories to the explanation of these phenomena; but in another contribution he made a fuller study of the problem. His later experiments (Bial, 1902) were again made with yeast cells, cultivated in fermentation tubes filled with grape-sugar solution to which various amounts of acid had been added; the antiseptic action was inversely registered by the amount of gas produced. The advantage of this method is its great delicacy; the fermentative power of the yeast responds to such extremely minute quantities of acid that the ionic effects are not complicated by other actions which appear in stronger solutions. Bial did not make exact calculations of the amount of dissociated hydrogen necessary to inhibit the yeast, but he found that a general relation existed between the ionization and the antiseptic action. The strongly dissociated acids — hydrochloric, sulphuric, nitric, and trichloracetic — entirely stopped the action of the yeast in concentrations of between 0.005 and 0.008 normal. Acids of an intermediate grade — phosphoric, formic, and oxalic — accomplished the same effect when 0.01 normal; while acids still less dissociated — acetic, benzoic, and butyric — stopped all fermentation only when 0.04 to 0.07 normal. The most striking feature of Bial's work was a series of experiments on the diminution of the antiseptic action of acids by the addition of neutral salts whose action is to decrease the dissociation of the acidic hydrogen. A solution of 0.01 normal formic acid and 0.3

normal sodium formate showed active fermentation, as did a solution of 0.0166 normal hydrochloric acid and 0.2 normal sodium chloride. The same phenomenon was observed with oxalates, nitrates, sulphates, and acetates. An exhaustive study in the case of hydrochloric acid showed that, while a certain amount of sodium chloride diminished the toxicity of the acid, a much larger amount actually increased it. Bial attributes this to a catalytic action of chlorine ions, but it seems to us that the facts may be explained more simply by the direct inhibiting effect of the sodium chloride and its ions. Bial found that twice normal sodium chloride without any acid prevented fermentation; and it is quite possible, in dealing with living organisms, that the combined effect of the acid and the chloride would be inhibitory at concentrations which with either acid or base alone might allow fermentation to go on. Bial studied also the effect of hydrochloric acid and sodium chloride in the presence of peptone, and found that the yeast would bear more of the salt than in the presence of acid alone.

The experiments of Paul and Krönig demonstrated clearly that in certain solutions disinfectant action runs parallel with the presence of dissociated ions. The work upon the higher plants and the mold fungi confirmed these results, but showed that in other cases the undissociated molecule is of great importance. Bial's studies brought out clearly the influence of neutral bodies, inorganic salts or proteids, in diminishing disinfectant action by decreasing dissociation.

The problem is, of course, complicated by still other chemical interactions which are more obscure. For example, Scheurlen (1895), Beckmann (1896), Römer (1898), and Spiro and Bruns (1898) have shown that in the case of phenol and certain other organic disinfectants the addition of sodium chloride greatly increases toxic action. Still another factor which affects disinfectant power has been brought out in recent years by Nägeli (1893), and other observers — the presence of suspended solid particles of neutral character. In the most recent communication upon this subject by True and Oglevee (1905) it was shown that the toxic effect of metallic salts upon *Lupinus* may be entirely counteracted by the presence of finely divided particles of sand, glass, filter paper, coal, starch, or paraffin. On the other hand, the toxic effect of organic disinfectants

— phenol, thymol, and resorcinol — was affected only to a barely appreciable degree. The action when it occurs is explained by the power of suspended particles to remove dissolved substances by a process of adsorption, and the possibility suggests itself that the removal of ions by large organic molecules in true or colloidal solutions may be of an analogous character. Whatever the cause, this phenomenon must prove of far-reaching importance in bacteriology. Such facts as the observed multiplication of bacteria, when water samples are stored in glass bottles, may be the result of a removal of inhibiting substances by the adsorptive action of glass surfaces.

A considerable body of evidence in the field of animal physiology bears out these conclusions obtained from the study of bacteria and other plants. A fairly full summary of this literature may be found in the reviews of Cohen (1903) and Hamburger (1904). The work of Kahlenberg (1898) and other observers, who have shown that the taste of dilute solutions is in many cases due to the specific properties of the dissociated ions, is of interest. Studies which have been frequently cited were made by Loeb (1897 and 1898), and recently reprinted (Loeb, 1905), on the influence of free ions upon frog's muscle. The gastrocnemius muscle absorbs water and increases its weight in the presence of slight traces of acids or alkalis, and Loeb concluded that for the inorganic acids and bases this increase in weight is solely a function of the number of hydrogen and hydroxyl ions in the unit of volume. This sweeping conclusion is hardly borne out by his experiments. With the organic acids there was no relation whatever. Trichloracetic acid, almost entirely dissociated, and lactic acid, with only 11 per cent. dissociation, gave practically the same results. With a series of 11 different organic acids of every degree of dissociation, the individal variation in weight-increase, with 0.009 normal solutions, ranged only between 3.9 per cent. and 7.2 per cent.

A very significant line of physiological investigation concerns the binding of free ions by organic molecules of large size. In one of the most recent communications on this subject, Stiles and Beers (1905) have shown that the effect of calcium chloride, barium potassium chloride, and sodium nitrite upon plain, cardiac, and striped muscle of the frog, terrapin, and guinea-pig was reduced from one-half to three-fourths in the presence of white of egg, partially dialyzed serum, peptone, or starch. In some cases a combination between the inorganic body and the proteid has been demonstrated by freezing-point determinations, but in other cases particularly with the neutral salts, this has not been shown. As the authors suggest, these experiments point to the existence of "*physiological compounds* which are not demonstrable at all by chemical methods, but only by the reactions of living tissues."

2. OBJECT AND METHODS OF THE PRESENT INVESTIGATION.

The present investigation was begun with the intention of determining the effect of acid wastes in sewage upon the viability of the typhoid bacillus under practical conditions. It soon appeared, however, that the problem was too complex to be attacked in any general way without the preliminary determination of certain of the individual factors involved, under definitely controlled conditions. We have therefore attempted to find the disinfectant power of two mineral acids and two organic acids upon the typhoid bacillus in tap water and in the presence of peptone, and have controlled these experiments by a parallel series with the colon bacillus. The results, besides their specific value as determinations of the reactions of these two organisms to dilute acids, have a certain interest in relation to the general theory of disinfection. In all the experiments reviewed above, except Bial's, the acids used were tested in only a few widely differing strengths, so that the parallelism between disinfectant action and dissociation was not established with any great exactness. In the work of Krönig and Paul on anthrax spores and the various studies on the mold fungi, it was necessary to use such strong solutions that ionic effects were largely masked by the influence of the undissociated molecule, and in the studies of Kahlenberg and True and Heald on the phanerogams it was evident that with such complex organisms many other factors than the direct effect on protoplasm come into play. There was room, therefore, for a series of experiments on organisms sensitive to very dilute acids, carried out in sufficient detail to show definitely the relations between toxicity and dissociation.

With the view of securing exact quantitative results, we adopted the method of exposure to the acid tested, in a suspension from which samples were directly plated. This process has the obvious defect of permitting a certain amount of the disinfectant to be carried over to the plate, where it may exert an antiseptic action. We have really measured the combined disinfectant action in the suspension and possible antiseptic action in the plate. The action of organic matter in decreasing toxicity, shown by our experiments, must greatly reduce any such action in the plate.

The procedure in each experiment was as follows: A series of bottles, each containing 100 c.c. of sterile water (or peptone solution), was arranged in a row, and to each bottle was added a different amount of standardized acid from a graduated pipette. The amount of water in each bottle was measured at the end of the experiment, in order to obtain the exact strength of the solution. Immediately after the addition of the acid there was added to each bottle 1 c.c. of a fresh aqueous suspension of the bacteria tested. After standing for 40 minutes, lactose agar plates were made in duplicate, from the acidified bottles, and from controls with no acid. Colonies were counted after 24 hours, incubation at 37° C.

Forty minutes was selected, after some preliminary experiments, as the best period of exposure to the acid, since it gave sharper results than a shorter time. In the tests reported in the accompanying tables there was not a variation from the 40 minutes of more than one minute in most of the samples. The series for *B. typhi* in water, with HCl, were also examined after 100 minutes, and after 24 hours. In the sample containing 48 parts per million of sulphuric acid, there was, after 40 minutes, 59.3 per cent. removal of *B. typhi*; after 100 minutes, 88.15 per cent. removal; after 24 hours, 100 per cent. removal. The sample containing 92.9 parts per million of sulphuric acid removed after 40 minutes 92.97 per cent.; after 100 minutes, 99.99+ per cent.; after 24 hours, 100 per cent. The removal was 100 per cent. in all of the samples containing larger amounts of acid after 103 minutes, and in all of the samples after 24 hours.

The temperature factor was of considerable importance, and care was taken to keep conditions uniform. No agar was poured with a temperature greater than 50° C. It was found that a rise in temperature in the presence of the acid was very fatal in its effect on the bacteria.

The typhoid culture used was obtained from the Massachusetts General Hospital, where it had been isolated from the spleen of a clinically typical case of typhoid fever; the colon bacillus was isolated in the laboratories of the Institute, and both gave all characteristic reactions. Twenty-four-hour agar-slant cultures were used in all cases.

The tables have been prepared to show, in the first column, the parts per million of the acid, and in the second column the parts per million of acidic hydrogen or, more accurately, of replaceable hydrogen. The third column shows the strength converted into terms of normality. The percentage dissociation of the acids at each dilution is given in the fourth column, and the actual parts of dissociated hydrogen in the fifth. The last two columns show the initial number of bacteria used as shown by blank controls and the percentage reduction after 40 minutes.

The tables show in general that with increasing quantities of disinfectant the bacterial reduction proceeds rapidly up to a certain point. After 99 per cent. of the organisms have been killed, however, it takes a very considerable further increase of acid to produce sterilization. This is a point of very fundamental importance, and one which has been observed in studying the effect of such various agents upon the bacteria, that it deserves special attention. Sedgwick and one of us (Sedgwick and Winslow, 1902) have called attention to the persistence of a few specially resistant individuals when typhoid bacilli are exposed to the action of cold. After 14 days of exposure to freezing temperature 99.8 per cent. of the organisms were killed, but after three months a few still survived. Johnson's tables of the reduction of typhoid and colon bacilli by copper salts (Johnson, 1905) show the same phenomenon, although he does not comment upon it specifically. More recently, Frost and Swenson (1906), and Gage and Stoughton (1906), have emphasized this peculiar phenomenon, in connection with resistance to high temperatures. The former authors, working with *B. dysenteriae*, found that "the majority of the cells were killed between 55° and 60°, but that frequently a relatively small number, possibly one individual in a hundred thousand or a million, may persist at much higher temperatures, even 70°." Gage and Stoughton in their conclusions point out that "the great majority of the bacteria in any *B. coli* cultures are destroyed by five minutes exposure to some temperature between 50° and 60° C. A few individuals, however, in each culture will survive much higher temperatures, in some cases remaining alive after exposure to 90° C. The very close range (about 10° C.) of temperature at which the destruction of the majority of the individual bacteria occurred, as compared with the considerable range (about 35° C.), in the temperatures at which complete sterilization was effected would indicate that the determination of the majority death-point would be of more value in species identification than is the determination of the absolute thermal death-point as at present employed."

Altogether it seems clear that among what are ordinarily considered non-sporing bacteria there exists a small proportion of individuals having specially high resistant powers against unfavorable conditions. The absolute death-point for these resistant forms is difficult to determine accurately on account of their small numbers and the consequent chances that they may be overlooked. We are inclined from our experience to agree with Gage and Stoughton as to the superior value for many purposes of the majority death-point (99 per cent.), and we shall lay special stress on this in interpreting our results.

3. THE DISINFECTANT ACTION OF HYDROCHLORIC ACID AND SULPHURIC ACID UPON *B. TYPHI* AND *B. COLI*.

Hydrochloric acid and sulphuric acid were chosen as types for the study of strong mineral acids, and the experiments were carried out as described above. The water used was Boston tap water, containing before sterilization about 40 parts per million of residue, 15 parts of hardness, 0.015 part of free ammonia, and 0.144 part of albuminoid ammonia. The results are shown in Tables 1–4.

The 99 per cent killing-point with the hydrochloric acid is reached at a strength of 0.0077 normal, with 7.49 parts of dissociated hydrogen per million, and the absolute killing-point, as nearly as it can be determined, with a 0.0123 normal solution containing 11.80 parts

TABLE 1.

ACTION OF HYDROCHLORIC ACID ON *B. coli* IN TAP WATER.

Acid parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
38.1	1.05	0.0010	98 0	1.03	40,000	00.00
77.6	2.13	0.0021	98.0	2.09	"	45.00
104.5	3.32	0.0033	97.5	3.24	"	72.85
149.0	4.08	0.0041	97.3	3.98	"	82.50
178.9	4.90	0.0049	97.2	4.76	"	97.50
281.0	7.71	0.0077	97.0	7.49	"	99.87
298.0	8.17	0.0082	96.5	7.99	90,000	99.96
377.0	10.61	0.0106	96 4	10.24	"	99.99
447.0	12.26	0 0123	96.4	11.80	"	100.00
515.0	....	....	96.3	....	"	100.00
590.0	....	....	96.3	....	"	100.00
663.0	....	....	96.2	....	"	100.00

TABLE 2.

ACTION OF SULPHURIC ACID ON *B. coli* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
45.9	0.94	0.0009	93	0.87	60,000	66.20
46.5	0.95	0.0009	93	0.87	140,000	80.00
111.5	2.28	0.0023	90	2.05	"	81.43
138.3	2.82	0.0028	89	2.51	60,000	86.50
176.6	3.62	0.0036	88	3.18	"	96.25
178.2	3.64	0.0036	88	3.20	140,000	82.14
225.2	4 59	0.0046	86	3.94	60,000	96.25
257.2	5.25	0.0052	85	4.46	"	98.50
311.5	6.36	0.0064	84	5.35	140,000	97.50
375.9	7.68	0 0077	83	6.38	"	98.86
470.0	9.60	0 0096	80	7.68	"	99.92
552.0	11 30	0.0113	79	8 93	"	99.92
630.0	12.90	0.0129	78	10.05	"	99.95
692.5	14.13	0.0141	77	10.90	"	99.95
812.0	16.57	0.0166	76	12.60	"	100.00
910.0	18.57	0.0186	75	13.95	"	100.00

of dissociated hydrogen. With the sulphuric acid the 99 per cent reduction was reached at a strength of 0.0096 normal, with 7.68 parts of dissociated hydrogen, and the 100 per cent reduction at a strength of 0.0166 normal, with 12.6 parts of dissociated hydrogen. These results show a direct relation between disinfectant action and free hydrogen ions. The normal strengths of the killing solutions do not correspond very closely; 0.0077 sulphuric acid failed to do what the same strength of hydrochloric acid did, and 0.0129 and 0.0141 sulphuric acid failed to do what 0.0123 hydrochloric acid did. On the other hand, when we compare dissociated hydrogen, allowing for the greater ionization of the hydrochloric acid, the discrepancies disappear. The same concentrations of dissociated hydrogen, within the limits of accuracy of the experiment, produced respectively the 99 per cent and the 100 per cent reduction in the two acids.

TABLE 3.

ACTION OF HYDROCHLORIC ACID ON *B. typhi* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
38.2	1.00	0.0010	98.2	1.02	7,050	79.20
75.3	2.06	0.0021	97.9	2.02	"	88.10
109.5	3.00	0.0030	97.8	2.94	"	99.30
148.2	4.06	0.0041	97.3	3.95	"	99.86
182.5	5.00	0.0050	97.1	4.85	"	100.00
216.8	5.92	0.0059	....	....	"	100.00
248.0	6.80	0.0068	....	....	"	100.00
275.5	7.54	0.0075	....	....	"	100.00

TABLE 4.

ACTION OF SULPHURIC ACID ON *B. typhi* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reducion of Bacteria after 40 Min.
48.0	0.98	0.0010	93.1	0.91	135,000	59.30
92.9	1.88	0.0019	90.5	1.70	"	92.97
139.4	2.84	0.0028	89.5	2.54	"	99.99
188.9	3.85	0.0038	87.0	3.35	"	96.10
223.0	4.55	0.0045	85.5	3.90	"	100.00

Tables 3 and 4 show that the typhoid bacillus is considerably more sensitive than the colon bacillus in its reaction to an excess of acid. The 99 per cent reduction was reached with hydrochloric acid at a strength of 0.0030 normal and 2.94 parts of dissociated hydrogen, and the 100 per cent reduction with 0.0050 normality and 4.85 parts of dissociated hydrogen. With sulphuric acid the 99 per cent reduction was reached with 0.0028 normality and 2.54 parts of hydrogen, and the 100 per cent reduction with 0.0045 normality and 3.90 parts of hydrogen. The fact that the 0.0038 normal solution of sulphuric acid showed only 96 per cent reduction is one of the abnormalities which unfortunately sometimes occur in bacteriological work. In general, the results show again that the two acids exert the same quantitative effect, although in this case, the solution being weaker and the dissociation of the two acids more nearly the same, the difference between normal strength and concentration of dissociated hydrogen is not clearly shown.

The critical points derived in these tests are brought together in Table 5. They show that the typhoid bacillus is a little less than half as resistant as the colon bacillus to dilute acids, and that the toxicity of these acids depends, not on their normal strength of acid or on the kind of acid used, but on the number of dissociated hydrogen ions. Between 7.4 and 7.7 parts of dissociated hydrogen effects a 99 per cent reduction of the colon bacillus, and between 11.8 and 12.6 parts, a 100 per cent reduction. For the typhoid bacillus the corresponding figures are 2.5–3.0 parts and 3.9–4.9 parts. Since at the dilutions used the hydrochloric acid was over 96 per cent dissociated, its effect must have been almost entirely ionic; and since the sulphuric acid at 75 per cent dissociation showed only the toxicity which would have been expected from its dissociated hydrogen, it appears that in this case too the undissociated molecule exerts no appreciable influence. The anions have been shown to be neutral in the experiments of other observers. It is evident, then, that the toxicity of these acids at high dilution is a function of the dissociated hydrogen.

TABLE 5.

DISINFECTANT ACTION OF MINERAL ACIDS IN TAP WATER.

	B. coli				*B. typhi*			
	99% Reduction		100% Reduction		99% Reduction		100% Reduction	
	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4
Normality	0.0077	0.0096	0.0123	0.0166	0.0030	0.0028	0.0050	0.0045
Parts per 1,000,000 dissociated hydrogen	7.49	7.63	12.80	12.60	2.94	2.54	4.85	3.90

4. THE DISINFECTANT ACTION OF ACETIC ACID AND BENZOIC ACID UPON *B. TYPHI* AND *B. COLI*.

We next desired to study examples of the incompletely dissociated organic acids. Acetic and benzoic acids were selected as types, and the experiments were carried out as before. The results obtained with benzoic acid are probably somewhat inaccurate on account of the difficulty of securing complete solution. The results are shown in Tables 6–8.

An inspection of these tables shows a marked difference from the results obtained with the mineral acids. With *B. coli* in acetic acid the 99 per cent reduction is reached at a strength of 0.0812 normal, and

TABLE 6.

ACTION OF ACETIC ACID ON *B. coli* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
111.3	1.85	0.0018	....	....	60,000	00.00
333.0	5.54	0.0055	6.40	0.35	"	00.00
552.0	9.18	0.0092	4.50	0.41	"	16.67
732.0	12.20	0.0122	3.50	0.43	"	23.33
1,095.0	18.25	0.0182	3.05	0.56	"	38.33
1,386.0	23.20	0.0232	2.75	0.64	"	51.67
1,825.0	30.41	0.0304	2.45	0.75	"	55.00
2,260.0	37.70	0.0377	2.20	0.83	"	56.67
3,081.0	51.40	0.0514	1.90	0.98	"	58.33
3,698.0	61.70	0.0617	1.70	1.05	"	63.33
4,800.0	80.20	0.0802	1.50	1.20	"	91.00
4,875.0	81.25	0.0812	1.50	1.21	90,000	99.99
5,610.0	93.50	0.0935	1.35	1.26	"	100.00

TABLE 7.

ACTION OF BENZOIC ACID ON *B. coli* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
237.9	1.95	0.0019	16.0	0.31	70,000	00.00
337.0	2.76	0.0028	13.6	0.38	"	50.00
406.0	3.33	0.0033	12.5	0.41	"	60.75
675.0	5.54	0.0055	9.3	0.52	"	67.80
1,184.0	9.72	0.0097	7.5	0.73	"	99.99
2,425.0	19.90	0.0199	5.4	1.07	100,000	100.00

TABLE 8.

ACTION OF BENZOIC ACID ON *B. typhi* IN TAP WATER.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
29.23	0.24	0.0002	40.0	0.10	50,000	44.00
140.30	1.15	0.0011	20.3	0.23	"	54.00
243.80	2.00	0.0020	15.4	0.31	"	62.00
333.00	2.73	0.0027	13.6	0.37	"	70.00
427.00	3.52	0.0035	10.4	0.37	"	92.00
689.00	5.75	0.0057	9.8	0.56	"	100.00
1,292.00	10.60	0.0106	7.2	0.76	"	100.00

the 100 per cent reduction at 0.0935 normal. The acid at these strengths is only a little over 1 per cent dissociated, and the amount of dissociated hydrogen present a little over 1.2 parts per million. Since this is only about one-sixth the strength of ionic hydrogen necessary to produce similar results with the mineral acids, it is evident that the toxic action of the acetic acids is due chiefly to the anion or the undissociated molecule, the latter, being so much greater in amount, probably playing the principal part. The same thing is true of benzoic acid. Here the molecule is more highly toxic, producing a 99 per cent reduction at 0.0097 normality and a 100 per cent reduction at 0.0199 normality, with about 1 per cent dissociation. As in the case of the mineral acids *B. typhi* is more sensitive than *B. coli*, showing 100 per cent reduction with benzoic acid at a strength of 0.0057 normal.

It appears, then, that the toxicity of these organic acids is due not mainly to hydrogen ions, but to the action of the undissociated molecule, varying widely, as might be expected, with the acid employed. A comparison of the corresponding toxic normal strength, made in Table 9, shows that benzoic acid is almost as toxic as the mineral acids, the effect being due in one case to the whole molecule, and in the other case to hydrogen ions. Acetic acid, on the other hand, has only 10–20 per cent as high a disinfectant action.

TABLE 9.

TOXICITY OF ORGANIC AND MINERAL ACIDS FOR *B. coli* AND *B. typhi*. STRENGTH IN NORMALITY PRODUCING 99 PER CENT AND 100 PER CENT REDUCTION.

	B. coli		*B. typhi*	
Acid	99% Reduction	100% Reduction	99% Reduction	100% Reduction
Hydrochloric.......	0.0077	0.0123	0.0030	0.0050
Sulphuric..........	0.0096	0.0166	0.0028	0.0045
Acetic..............	0.0812	0.0935	......	......
Benzoic...........	0.0097	0.0199	.....	0.0057

5. THE DIMINISHED TOXICITY OF ACIDS IN THE PRESENCE OF PEPTONE.

Having fixed with some precision the killing-point for the various acids studied, when acting in tap water, we next desired to determine what would occur in the presence of organic matter. A series of experiments was carried out, parallel to those reported above, except that a 1 per cent solution of Witte's peptone was used instead of tap water. The results with the mineral acids, presented in Tables 10–12, showed that the toxicity of the acid is profoundly modified by the presence of organic matter.

TABLE 10.

DISINFECTANT ACTION OF HYDROCHLORIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c. c. before treatment	Percentage Reduction of Bacteria after 40 Min.
1,118	30.62	0.0306	94.8	29.0	90,000	40.00
1,825	50.00	0.0500	94.8	47.5	"	93.35
2,502	69.00	0.0690	93.0	64.2	"	97.97
2,950	80.80	0.0808	92.0	74.4	"	97.74
3,470	95.20	0.0952	91.5	87.5	"	99.98
3,685	97.80	0.0978	91.4	89.4	"	100.00
4,020	110.00	0.1100	....	....	"	100.00

TABLE 11.

DISINFECTANT ACTION OF SULPHURIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c. c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
970	.....	.....	....	....	140,000	00.00
1,204	.....	....	....	....	"	00.00
1,405	.....	....	....	....	"	00.00
1,536	31.4	0.0314	70.0	22.0	"	00.00
1,728	35.3	0.0353	68.5	24.2	"	20.00
1,962	40.1	0.0401	67.5	27.1	"	61.43
2,066	40.9	0.0409	67.0	27.4	"	64.29
2,399	48.9	0.0489	65.4	32 0	60,000	76.67
2,639	53.8	0.0538	64.8	24.9	"	79.17
2,912	59.4	0.0594	64.2	38.1	"	91.67
3.065	62.6	0.0626	63.2	30.6	"	93 33
3,258	66.5	0.0665	62.8	41.8	"	94.17
3,450	70.4	0.0700	61.9	43.5	"	98.85
4,610	94.2	0.0942	58.9	55.5	65,000	99.99
5,298	108.1	0.1081	57.0	61.6	"	100.00
6,555	135.2	0.1352	....	....	"	100.00
7,800	159.3	0.1593	....	....	"	100.00

TABLE 12.

DISINFECTANT ACTION OF HYDROCHLORIC ACID ON *B. typhi* IN 1 PER CENT PEPTONE SOLUTION

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c. c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
1,107	30.3	0.0330	94.8	28.7	50,000	99.99
1,740	47.6	0.0476	93.8	44.6	50,000	100.00

In these tables the dissociation values given are those determined for distilled water, and not those which actually obtain in a peptone solution. The amount of dissociated hydrogen required for disinfection, when estimated in this way, is seen to be nearly 10 times as great as in tap water. For comparison the results are brought together in Table 14.

TABLE 13.

DISINFECTANT ACTION OF SULPHURIC ACID ON B. *typhi* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrgen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c. c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
819	17.03	0.0170	74.5	12.7	85,000	00.00
960	20.00	0.0200	73.7	14.7	"	17.65
1,104	22.52	0.0225	72.0	16.2	"	17.65
1,139	23.17	0.0232	72.0	16.7	"	34.10
1,288	26.32	0.0265	71.0	18.7	"	61.20
1,453	29.63	0.0296	70.2	20.8	28,000	82.15
1,472	30.03	0.0300	70.1	21.0	85,000	76.45
1,519	31.66	0.0317	69.7	21.6	28,000	89.30
1,587	32.39	0.0324	69.5	22.5	"	89.30
1,612	32.89	0.0329	69.0	22.7	"	100.00
1,678	34.24	0.0342	68 5	23.4	"	97.86
1,879	38.32	0.0383	68.0	26.0	"	100.00
1,994	.....	......	....	....	"	100.00
2,045	.....	......	....	....	"	100.00
2,115	.....	......	....	....	"	100.00
2,119	.....	......	....	....	"	100.00
2,399	.....	......	....	....	"	100.00

TABLE 14.

COMPARATIVE TOXICITY OF MINERAL ACIDS IN DISTILLED WATER AND 1 PER CENT PEPTONE SOLUTION

(Parts per 1,000,000 of dissociated hydrogen.)

	B. coli				*B. typhi*			
	99% Reduction		100% Reduction		99% Reduction		100% Reduction	
	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4	HCl	H_2SO_4
Distilled water........	7.49	7.68	11.80	12.60	2.94	2.54	4.85	3.90
1 per cent peptone....	87.5	55.5	89.4	61.6	28.7	....	44.6	22.7

It is evident that in some way the peptone exerts a strong influence in counteracting the toxic effect of the acids. It at first occurred to us that this might be due simply to the fact that peptone solution furnished a more favorable medium for the bacteria, and thus enabled them to resist unfavorable conditions. Such an effect would, however, hardly be expected in so short a period as 40 minutes; and this explanation fails to account for the fact that the toxicity of the hydrochloric acid is much more diminished than that of the sulphuric acid. Reference to Tables 15–17, which show the results obtained with the organic acids, makes it still clearer that a specific chemical action is involved.

Evidently with the organic acids disinfectant power is much less affected by the presence of peptone. With *B. coli* acetic acid produces a 100 per cent reduction when in a strength of 0.0935

TABLE 15.

DISINFECTANT ACTION OF ACETIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION.

Acid .Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
4,350	72.5	0.0725	1.60	1.16	50,000	00.00
4,750	79.3	0.0793	1.50	1.19	"	00.00
5,340	89.0	0.0890	1.40	1.25	"	25.00
5,975	97.0	0.0970	1.30	1.26	"	66.00
5,995	98.0	0.0980	1.30	1.27	"	61.72
6,861	114.2	0.1142	1.25	1.42	65,000	98.75
7,540	125.8	0.1258	1.15	1.45	"	93.30
8,360	139.5	0.1395	1.05	1.46	"	100.00
9,125	152.1	0.1521	1.03	1.57	"	100.00
16,475	174.5	0.1745	1.00	1.75	"	100.00
10,720	178.8	0.1788	1.00	1.78	"	......
......	210.0	0.2100	....	....	"	......
14,620	244.0	0.2440	0.90	2.20	"	100.00

TABLE 16.

DISINFECTANT ACTION OF BENZOIC ACID ON *B. coli* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1,000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
1,638	13.18	0.0132	6.4	0.84	70,000	28.6
1,720	14.11	0.0141	6.2	0.87	70,000	28.6
2,105	17.20	0.0172	5.8	1.00	100,000	0.0
3,365	27.60	0.0276	5.2	1.43	100,000	73.0
5,555	47.30	0.0473	3.2	1.51	100,000	100.0

TABLE 17.

DISINFECTANT ACTION OF BENZOIC ACID ON *B. typhi* IN 1 PER CENT PEPTONE SOLUTION.

Acid Parts in 1.000,000	Hydrogen Parts in 1,000,000	Normality	Per Cent of Dissociation	Dissociated Hydrogen. Parts in 1,000,000	Bacteria per c.c. before Treatment	Percentage Reduction of Bacteria after 40 Min.
1,434	11.72	0 0117	6.9	0.81	50,000	20.00
1,562	12.80	0 0128	6.6	0.84	50,000	20.00
2,155	17.80	0.0178	5.7	1.01	56,000	81.43
2,917	24.30	0.0243	4.9	1.19	56,000	100.00

normal. In the presence of peptone the required strength is 0.1395 normal. With *B. coli* the corresponding 100 per cent reduction strengths for benzoic acid are 0.0199 in water and 0.0473 in peptone solution. With *B. typhi* the respective strengths of benzoic acid are 0.0057 and 0.0243.

In a general way we may say that the presence of 1 per cent peptone solution diminishes the toxicity of hydrochloric acid, measured in terms of dissociated hydrogen, to from one-eighth to one-tenth its water value, and that of sulphuric acid to from one-fifth to one-eighth its water value. The toxicity of benzoic acid, measured in normality, is diminished under the same conditions to from one-fourth to one-half, and that of acetic acid to a little over one-half its water value.

The most probable explanation of this phenomenon is the formation of a loose compound between the proteid molecules and the acids which would diminish the toxicity of the latter, just as Stiles and Beers (1905) have shown that such a combination alters the effect of mineral salts on muscle.

Bugarzky and Liebermann (1898), Cohnheim and Krieger (1900), and other observers, have proved the existence of such loose compounds between proteids and acids by freezing-point determinations. We desired, however, to examine the actual substance used in our own experiments. Through the kindness of Dr. Raymond Haskell, of the Research Laboratory of Physical Chemistry of this Institute, determinations of electrical conductivity were made on the peptone solution used in our experiments, on a solution of hydrochloric acid in distilled water, and on a solution of the same strength in the peptone solution.

The specific conductivity of the peptone solution was 0.0004, showing that it was fairly pure. That of the hydrochloric acid solution 0.02 normal or 720 parts HCl per million, 90.46 per cent dissociated, was 0.007. The 1 per cent peptone solution containing 0.02 normal hydrochloric acid gave a conductivity of 0.002, showing that approximately four-fifths of the hydrochloric acid had been neutralized by the peptone.

It is evident that the effect of the peptone in decreasing the toxicity of the hydrochloric acid may be explained by the fact that the number of dissociated hydrogen ions is decreased by the peptone in the same degree. The effect would naturally be less marked, as we find to be the case, with sulphuric acid, since this acid is less ionized to start with. Finally, the un-ionized organic acids are least affected. The decreased toxicity which does occur with them may perhaps be due to a loose compound with their whole-molecule — what Stiles and Beers call a "physiological compound."

6. GENERAL CONCLUSIONS.

It appears from our experiments that the typhoid bacillus is highly sensitive to an excess of acid, being destroyed in an aqueous suspension by 40 minutes, exposure to a 0.005 normal solution of either hydrochloric, sulphuric or benzoic acid. The colon bacillus will endure exposure, under similar conditions, to solutions from two to four times as strong. Ninety-nine per cent of the bacteria in a suspension are killed by solutions of from one-half to two-thirds this strength, the last few organisms being especially resistant.

The mineral acids, hydrochloric and sulphuric, are fatal in concentrations at which they are highly dissociated. Their action runs parallel, not to their normal strength, but to the number of free hydrogen ions per unit volume. With the two organisms tested, both the 99 per cent and the 100 per cent reductions were affected, at the same concentration of dissociated hydrogen, whichever acid was used.

The organic acids, acetic and benzoic, are fatal to the typhoid and colon bacilli at a strength at which they are only slightly dissociated. The effect here appears to be due to the whole-molecule and is specific for each acid, acetic having only 10–20 per cent the toxicity of benzoic.

The presence of 1 per cent of peptone greatly diminishes the toxic action of acids, the action being somewhat less marked with sulphuric acid than with hydrochloric, and still weaker with the organic acids. In the case of hydrochloric acid we find that the diminished toxicity is accounted for by decreased ionization.

It is evident that the action of organic matter and other neutral substances in decreasing toxicity greatly complicates the study of disinfectant action. It will be necessary to bear this phenomenon in mind in considering the composition of culture media, since the apparent acidity, as determined by titration, may be quite different from the effective acidity which influences living organisms. With the mineral acids, any factor which affects dissociation, such as the presence of neutral salts of the same anion, will change the effective acidity. In considering the viability of disease germs in sewage and water, it is evident that differences in dilution and the effect of inorganic salts, organic matter, and suspended solids introduce such complex factors that detailed studies of specific local conditions are desirable.

REFERENCES.

BECKMANN, J. W. 1896. Ueber den Einfluss des Zusatzes von Chlornatrium auf die Wirkung des Phenols. *Centralbl. f. Bakt.*, Abth. I, 20, p. 577.

BEHRING. 1890. Ueber Desinfection, Desinfectionsmittel und Desinfectionsmethoden. *Ztschr. f. Hyg.*, 9, p. 395.

BIAL, M. 1897. Ueber den Mechanismus der Gasgährungen im Magensafte. *Arch. f. exper. Path. u. Pharm.*, 38, p. 1.

BIAL, M. 1902. Ueber die antiseptische Funktion des H-Ions verdünnter Saüren. *Ztschr. f. phys. Chemie.*, 40, p. 513.

BUGARSZKY, S., AND LIEBERMANN, L. 1898. Ueber das Bindungsvermögen eiweissartiger Körper für Salzaüre, Natriumhydroxid und Kochsalz. *Arch. f. d. ges. Physiol.*, 72, p. 51.

CLARK, J. F. 1899. On the Toxic Effect of Deleterious Agents on the Germination and Development of Certain Filamentous Fungi. *Bot. Gazette*, 28, p. 289; also, *Jöur. Phys. Chem.*, 3, p. 203.

COHEN, E. 1903. Physical Chemistry for Physicians and Biologists. Trans. by M. H. Fischer, New York, 1903.

COHNHEIM, O., AND KRIEGER, H., 1900. Das Verhalten der Eiweisskörper zu Alkaloidreagentien zugleich eine Bestimmung der gebundenen Salzsaüre. *Ztschr. f. Biol.*. 40, p. 95.

DRESER, H. 1893. Zur Pharmakolcgie des Quecksilbers. *Arch. f. exper. Path. u. Pharm.*, 32, p. 456.

FROST, W. D., AND SWENSON, M. W. 1906. Note on the Thermal Death-Point of *B. dysenteriae* Shiga. *Science*, N. S., 23, p. 216.

GAGE, S. D., AND STOUGHTON, G. VAN E. 1906. A Study of the Laws Governing the Resistance of *B. Coli* to Heat. *Science*, N. S., 23, p. 216.

HAMBURGER, H. J. 1904. Osmotischer Druck und Ionlehre in den medicinischen Wissenschaften. Wiesbaden, 1904.

HEALD, F. D. 1896. On the Toxic Effect of Dilute Solutions of Acids and Salts upon Plants. *Bot. Gazette*, 22, p. 125.

HEIDER, A. 1892. Ueber die Wirksamkeit der Desinfectionsmittel bei erhöhter Temperatur. *Arch. f. Hyg.*, 15, p. 341.

JOHNSON, G. A. 1905. The Use of Copper Sulphate for Reducing the Pathogenicity of Sewage and Sewage Effluents. *Jour. New Eng. Waterworks Assoc.*, 19, p. 506.

KAHLENBERG, L. 1898. The Action of Solutions on the Sense of Taste. *Bull. University of Wisconsin*, 2, p. 1.

KAHLENBERG, L., AND TRUE, R. H. 1896. On the Toxic Action of Dissolved Salts and Their Electrolytic Dissociation. *Bot. Gazette*, 22, p. 81.

KOCH, R. 1881. Ueber Desinfection. *Mitth. a. d. kaiserlichen Gesundheitsamte*, 1, p. 1.

KRÖNIG, B., AND PAUL, T. 1897. Die chemischen Grundlagen der Lehre von der Giftwirkung und Desinfection. *Ztschr. f. Hyg.*, 25, p. 1.

LOEB, J. 1897. Physiologische Untersuchungen über Ionenwirkungen, I. *Arch. f. d. ges. Physiol.*, 69, p. 1.

LOEB, J. 1898. Physiologische Untersuchungen über Ionenwirkungen, II. *Arch. f. d. ges. Physiol.*, 71, p. 457.

LOEB, J. 1905. Studies in General Physiology. *Decennial Publications of the University of Chicago*, Chicago, 1905.

MAILLARD, L. 1898. Du rôle de l'ionisation dans les phénomènes vitaux. *Comptes rend. de la Soc. de Biol.*, 50, p. 1210.

MAILLARD, L. 1899. Rôle de l'ionisation dans la toxicité des sels métalliques; sulfate de cuivre et *Penicillium glaucum*. *Bull. Soc. chim. Paris*, 21, p. 26.

MINERVINI, R. 1898. Ueber die baktericide Wirkung des Alkohols. *Ztschr. f. Hyg.*, 29, p. 117.

NÄGELI, C. VON. 1893. Ueber oligodynamische Erscheinungen in lebenden Zellen. *Neue Denkschriften der allgemeinen Schweizerischen Gesells. f. d. ges. Naturwissenschaften*, 33, Abth. 1.

PAUL, T., AND KRÖNIG, B., 1896. Ueber das Verhalten der Bakterien zu chemischen Reagentien. *Ztschr. f. phys. Chemie*, 21, p. 414.

RÖMER, C. 1898. Ueber Desinfection von Milzbrandsporen durch Phenol in Verbindung mit Salzen. *Münch. med. Wchnschr.*, 45, p. 298.

SCHEURLEN. 1895. Die Bedeutung des Molecularzustandes der wassergelösten Desinfectionsmittel für ihren Wirkungswerth. *Arch. f. exper. Path. u. Pharm.*, 37, p. 74.

SCHEURLEN AND SPIRO. 1897. Die gesetzmässigen Beziehungen zwischen Lösungszustand und Wirkungswerth der Desinfectionsmittel. *Münch. med. Wchnschr.*, 44, p. 81.

SEDGWICK, W. T., AND WINSLOW, C.-E. A. 1902. Experiments on the Effect of Freezing and Other Low Temperatures upon the Viability of the Bacillus of Typhoid Fever, with Considerations, Regarding Ice as a Vehicle of Infectious Disease. *Memo. Amer. Acad. Arts and Sciences*, 12, p. 471.

SPIRO, K., AND BRUNS, H. 1898. Zur Theorie der Desinfection. *Arch. f. exper. Path. u. Pharm.*, 41, p. 355.

STEVENS, F. L. 1898. The Effect of Aqueous Solutions upon the Germination of Fungus Spores. *Bot. Gazette*, 26, p. 377.

STILES, P. G., AND BEERS, W. H. 1905. On the Masking of Familiar Ionic Effects by Organic Substances in Solutions. *Amer. Jour. Physiol.*, 14, p. 133.

TRUE, R. H., AND OGLEVEE, C. S. 1905. The Effect of the Presence of Insoluble Substances on the Toxic Action of Poisons. *Bot. Gazette*, 39, p. 1.

WÜTHRICH. 1892. Ueber die Einwirkung von Metallsalzen und Saüren auf die Keimfähigkeit der Sporen einiger der verbreitetsten parasitischen Pilze unserer Culturpflanzen. *Ztschr. f. Pflanzenkrankheiten*, 2, p. 17.

[REPRINTED FROM THE JOURNAL OF THE AMERICAN CHEMICAL SOCIETY,
VOL. XXVIII. No. 3. MARCH, 1906.]

THE DETERMINATION OF SMALL QUANTITIES OF COPPER IN WATER.

(Published by permission of the Director of the U. S. Geological Survey.)

BY EARLE B. PHELPS.

Received January 11, 1906.

DURING the past few years the question of the addition of small quantities of copper salts to water supplies as a preventative of algal growths and as an emergency disinfectant against typhoid fever germs, has received much discussion and led to many important investigations in this country as well as abroad. One result of all this work has been to indicate the need of some simple yet accurate method for the determination of the small amounts of copper with which the investigator has to deal. The method recommended by the Committee on Standard Methods of Water Analysis of the Laboratory Section of the American Public Health Association,[1] is essentially that of Clark and Forbes.[2] It involves the concentration of a sufficient amount of the water to yield a weighable amount of copper, the precipitation of the copper as well as of certain other metals which may be present, as sulphides, and the separation from the mixed sulphides of the lead and iron by the usual methods. The copper is then deposited electrolytically and weighed. Quantities of copper as small as 2 or 3 mg. are thus determined by Clark and Forbes with a mean probable error of about 5 per cent., while the determination of 1 mg. obviously cannot be made with a probable error of less than 10 per cent. The disadvantages of the process are, first, the necessity for boiling down a large volume of water in order to get sufficient copper to weigh with accuracy, and, second, the length of time required and the liability of error introduced by the precipitations and separations involved.

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[1] "Report of the Committee on Standard Methods of Water Analysis," Jour. Inf. Dis. 1905, Sup. No. 1, p. 1.

[2] Mass. State Board of Health, 32d Ann. Rep. for 1900, p. 487.

Colorimetric methods, while generally much more sensitive than the gravimetric, are greatly influenced by the presence of other substances, especially other metals and organic coloring-matter.

The writer has had occasion to make a number of such copper determinations and was moreover limited by the experimental conditions to quantities of one liter for each determination. Since the water contained at times only a few tenths of a milligram of copper per liter, the standard method of procedure was obviously out of the question. As a result of a study of various possible methods for the determination, a procedure was devised which seemed to combine to a satisfactory degree the requisite sensitiveness, accuracy and simplicity. The method consists in the evaporation of a given volume of the water to about 100 cc. the electrolytic separation of the copper from the acidulated solution, the solution of the deposited copper in dilute acid, and its neutralization and colorimetric determination as sulphide, by comparison with standard tubes of known copper content. By this procedure it is easily possible to determine 0.1 mg. of copper, or if this amount were derived from a liter of water, 0.1 part per million. The accuracy is fully as great as with the gravimetric method using ten times as much of the same water.

The detailed procedure is as follows:

Apparatus.— Platinum dishes of about 100 cc. capacity to serve as anodes. Connection with the circuit is most conveniently made by placing the dish in a little mercury, contained in a shallow metal dish. To the latter is soldered a wire leading to the positive binding post.

A stout platinum wire, about 50 cm. long, 40 cm. of which is coiled into a flat spiral and whose end is fastened directly to the negative binding post. The spiral constitutes the cathode.

A convenient source of electrical current. The character of the current is not so important in this case as in gravimetric processes, since only small amounts of copper are dealt with and

SUMMARY OF COPPER DETERMINATIONS.

No.	Water.	Parts per million.		Characteristics of the water.	Substances added.	Mg. of copper.	
		Total solids.	Loss on ignition.			Taken.	Found.
1	Boston tap water....	40	15	Soft, colored, surface.	None.	0.54	0.52
2	Boston tap water....				None.	0.27	0.27
3	Boston tap water....				None.	0.27	0.24
4	Boston tap water....				None.	0.14	0.12
5	Boston tap water....				None.	0.14	0.12
6	Boston tap water....				Fe as $FeCl_3$, 5 mg.; Pb as acetate, 40 mg.	0.54	0.54
7	Boston tap water....				Ag as $AgNO_3$, 0.5 mg.; Sn as $SnCl_2$, 1.0 mg.	0.54	0.57
8	Chattahoochee, Ga..	300	50	Soft; solids are red iron clay.	None.	0.54	0.57
9	Pecos, N. Mex......	2000	100	Hardness of 840 parts; turbid.	None.	0.54	0.54
10	Milk, Mont.........	750	....	Hardness of 620 parts; clear.	None.	0.54	0.55
11	Colorado, Tex.......	300	....	Hardness of 128 parts; turbidity of 110.	None.	0.54	0.52
12	Boston sewage......	4000	810	Chlorine abnormal, about 1500.	None.	0.54	0.50
13	Hay infusion........	....	....	Color about 300.	None.	0.54	0.55
14	Straw board waste...	7000	4000	High in CaO and organic acids.	None.	0.54	0.51

the deposit need not be washed or dried. In the present experiments the current was supplied by two "gravity cells" in series, yielding a current through the solution of about 0.02 ampere. The current density at the cathode was about N. $D_{100}=0.3$ ampere.

Nessler jars of the short type holding 100 cc.

Reagents.—Standard copper solution. About 0.8 gram of clean copper sulphate crystals are dissolved in water and, after the addition of 1 cc. concentrated sulphuric acid, the volume is made up to one liter. In 100 cc. of this solution the copper is determined in the usual way by electrolytic deposition and weighing and the solution is diluted so that 1 cc. contains 0.2 milligram copper. This solution is permanent.

Potassium sulphide reagent. An alkaline solution of potassium sulphide made by mixing equal volumes of 10 per cent. potassium hydroxide solution, and a saturated solution of hydrogen sulphide in water.

Nitric acid one to three and sulphuric acid one to one, both tested for copper.

The Determination.—Of waters carrying from 0.1 to 1.0 part copper one litre is taken. For other concentrations take proportionate amounts. Evaporate to about 75 cc. and wash into the platinum dish. Add 2 cc. of the dilute H_2SO_4 for clear and soft waters. For alkaline waters an additional amount is used to offset the alkalinity. For waters carrying much organic matter or clay, 5 cc. of acid are added to assure the formation of a soluble copper salt. The dish is then placed in position, the cathode suspended in the solution so that it is parallel to and about half an inch from the bottom, and the circuit is closed. Electrolyze for about four hours with occasional stirring, or over night, if convenient. Lift out the cathode without previously having opened the circuit, and immerse the spiral in a small amount of the dilute nitric acid, previously heated to boiling. Wash off the wire and evaporate the nitric acid solution to dryness on the water-bath. If silver is suspected to be present, add a few drops of hydrochloric acid before evaporation. Take up in water and wash into the Nessler jar. Make up to the mark and add 10 cc. of the sulphide reagent. The color of the copper sulphide develops at once and is fairly permanent, lasting for several hours, at least. A similar tube is prepared by adding 10 cc. of the reagent to a tube of distilled water and then adding standard copper solution in 0.2 cc. portions until the colors of the two tubes match. If one litre of water were originally taken, each cubic centimeter of standard solution used represents 0.2 part per million of copper.

The method has been carefully tested as to the completeness of the separation and as to the influence of other substances in the water. Particular care has been taken to separate small amounts of copper from large amounts of organic matter (sewage and industrial wastes), coloring-matter in surface waters, and from salts of iron, lead, silver and tin. As will be seen from the appended table of results the separation is in all cases satisfactory. Silver and tin appear to be, according to the authorities, the only metals which will separate out under the conditions used. Neither will be commonly met with. The silver may be converted into the chloride as indicated and does not interfere with the determination. The tin is only partially dissolved by the nitric acid and during the evaporation is converted into metastannic acid. In the alkaline solution used in the test the tin in this form does not interfere in the least.

In the accompanying table are given the results obtained in testing this method. In all cases except those in which Boston sewage and straw-board liquor (the waste liquor of a straw-board mill) were used, one litre of water was taken and the necessary solutions added to it. In the two cases mentioned only 100 cc. were taken.

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THE INHIBITING EFFECT OF CERTAIN ORGANIC SUBSTANCES UPON THE GERMICIDAL ACTION OF COPPER SULPHATE.*

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INTRODUCTION.

THE germicidal action of copper salts dissolved in water has frequently been found to depend largely upon the character of the water itself. Ellms (1905) has pointed out the influence of the hardness and turbidity of the water. Johnson and Copeland (1905) found that in a sewage effluent, to which a large number of typhoid organisms had been added, an amount of copper sulphate equal to a concentration of 20 parts of copper per million reduced the number of bacteria from 1,300,000 to 600 per cubic centimeter in 15 hours. In distilled water, other conditions being the same, the reduction was from 1,300,000 to 11. Kraemer (1905) and Basset-Smith (1905) have both shown that the toxic action of copper on the typhoid organism is much greater in distilled water than in tap water.

It is not difficult to determine the nature of the influence exerted by mineral impurities in the water. Dissolved carbonates bring about a direct precipitation of the copper. Even such insoluble material as kaolin has been shown by Sullivan (1905) to possess the power of reacting with copper salts, in some cases completely removing the copper from solution. True and Oglevee (1905) have confirmed the earlier results of Nägeli showing that adsorption often plays an important rôle, and that powdered glass or sand may destroy in large measure the toxic action of dilute metallic solutions.

In case of organic impurities the nature of the influence is not quite so clear. Direct precipitation of the copper may occur, especially in sewages. On the other hand, the presence of certain classes of organic matter, such as leaf infusion, has been shown to prevent the precipitation of copper by alkaline carbonates (Ellms, 1905). In such

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*Received for publication March 28, 1906.

cases it must be assumed that certain organic compounds are formed. If such compounds are found upon investigation to be non-toxic, or to have a lower toxic value than the original copper salt, this fact may throw some light upon the nature of the toxic action itself.

It was the purpose of the present investigation to study the germicidal action of copper sulphate upon the typhoid organism in distilled water and in the presence of certain organic compounds. Organic substances were selected which would not in any case precipitate the copper, and which, according to the chemical evidence, do not form any direct union with it. This does not preclude the formation of a "physiological compound," as defined by Stiles and Beers (1905), namely, a compound which is not readily detectible by chemical means, but which possesses characteristic physiological properties. For this purpose dextrose and peptone were used. The organic matter occurring naturally in Boston tap water, a colored surface water, was also studied.

METHODS.

Preparation of copper sulphate.—The copper sulphate used was carefully prepared to assure a pure product. In particular was it desired to obtain salt free from ammonia, since there is reason to believe that the double or cuprammonium salt will have a distinctly different toxic effect from that of the simple copper salt. Some "C. P." copper sulphate crystals were dissolved in water, making about a 10 per cent solution. To this solution a small amount of Na_2CO_3 was added, and the solution was boiled for some time to expel the ammonia. It was then acidified and submitted to electrolysis with a small current, about 0.05 ampere, and a potential difference through the solution of about one volt. Copper was deposited on the inside of a platinum dish which served as a cathode. This deposit of copper was then washed with ammonia-free water and redissolved in dilute sulphuric acid by reversing the current. The product obtained by crystallizing this solution was recrystallized from ammonia-free water to free it from the last traces of acid. It was dried for several days over calcium chloride and caustic potash.

Preparation of potassium sulphate.—This salt was prepared by twice recrystallizing the best Merck preparation from ammonia-free water.

Tenth-molar (fifth-normal) solutions of these salts were made up. For use 1 c.c. of these solutions was diluted to 100 with ammonia-free water. In the following tabulated results all references to the salt solutions are to these dilute (N/500) solutions.

The organic compounds.—Witte's peptone and Merck's "C. P." dextrose were used.

The typhoid cultures.—The culture used (No. 2006) was one of those used in some earlier work. It was obtained from Dr. J. H. Wright, of the Massachusetts General Hospital. It was taken from the spleen at an autopsy on May 26, 1905. The clinical diagnosis was typhoid fever. The culture, according to Wright, gave all the ordinary tests for typhoid fever, including the Widal test.

It was submitted to the ordinary diagnostic tests, with the following results: fermentation tube with dextrose broth, growth in closed arm, acid produced, no gas; milk not coagulated, slight acid production; no indol from peptone; nitrates reduced slightly; gelatin not liquefied in two weeks; growth on agar slant, scanty, thin, translucent; it reacts with the sera of two rabbits into which two other strains of typhoid organisms had been introduced subcutaneously.

Cultures A, B, and C were obtained from plates made from Bottle 2 in Experiment 5. They had lived for 48 hours in the presence of a concentration of 0.63 parts of copper per million in distilled water. They gave all the above tests exactly as the original culture, except that they were not submitted to the Widal test.

Technique of the experiments.—The experiments were made under as uniform conditions as possible, and in the following manner:

In all cases, except where tap water is specified, sterilized ammonia-free water was used. When dextrose or other solutions were used, these were made up with ammonia-free water and sterilized. The organism was grown for 24 hours at 37° on the surface of an agar slant. A loop of the culture was then removed and placed in 100 c.c. of water. After thorough shaking, proper amounts of this suspension were added to the bottles of water in which the experiments were to to be made. These bottles were then thoroughly shaken, and the the bacteria determined in each by properly diluting 1 c.c. and plating. For plating agar was used, and all plates were grown for 15 hours at 37° C. The salt solution was then added. In the same manner determinations of the numbers of organisms present were made at intervals during the experiment, as indicated in the tabulated results.

In the following tables the full details of each experiment are first given, including the actual bacterial counts. In order to compare the various experiments, the bacterial results have been calculated

EXPERIMENT 1.

STARTED JANUARY 24, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	COUNTS			
						Initial	5 Min.	64 Hrs.	24 Hrs.
1	98	0.6	...	12	0.38	380,000	125,000	6,000	42
2	98	1.0	...	20	0.63	400,000	45,000	1,700	12
3	100	2.0	...	40	1.26	350,000	25,000	300	9
4	98	...	0.6	12	....	370,000	......	370,000	50,000
5	98	...	1.0	20	....	410,000	......	460,000	45,000
6	99	...	2.0	40	....	400,000	......	400,000	43,000

Temperature, 20°–22°.

EXPERIMENT 2.

TAP WATER—STARTED JANUARY 29, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ So. (c.c.)	K_2SO_4 So. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	COUNTS					
						Initial	1 Min.	10 Min.	30 Min.	6 Hrs.	29 Hrs.
1	89	0.4	...	8.8	0.28	170,000	180,000	170,000	170,000	110,000	9,800
2	94	0.8	...	16.8	0.53	180,000	......	......	......	50	510
3	84	1.2	...	28.0	0.88	190,000	......	......	......	......	100
4	90	2.0	...	44.0	1.39	150,000	......	......	......	......	80
5	88	3.0	...	66.0	2.08	180,000	120,000	100	100	50	0
6	88	...	0.4	8.8	....	140,000	......	......	......	......	240,000
7	89	...	0.8	18.0	....	160,000	......	......	......	......	336,000
8	90	...	1.2	26.0	....	180,000	......	......	......	......	92,000
9	95	...	2.0	42.0	....	170,000	......	......	......	......	69,000
10	92	...	3.0	66.0	....	200,000	......	......	......	......	80,000

Temperature, 20°–23°.

EXPERIMENT 3.

STARTED FEBRUARY 6, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	COUNTS			
						Initial	1 Hr.	6 Hrs.	24 Hrs.
1	100	0.5	...	10	0.31	125,000	.....	5,300	8
2	99	1.0	...	20	0.62	135,000	.....	700	6
3	105	2.0	...	40	1.24	140,000	.....	400	9
4	98	3.0	...	60	1.86	128,000	80,000	130	0
5	99	...	0.5	10	....	140,000	.....	120,000	80, 000
6	97	...	1.0	20	....	136,000	.....	100,000	70'000
7	98	...	2.0	40	....	132,000	.....	100,000	63 ,000
8	98	...	3.0	60	....	140,000	.....	120,000	56,000

Temperature, 20°–22°.

into percentage of the initial numbers, and these results have been used in the discussion of the table.

In each case in which copper sulphate was used the control contained an equimolar amount of potassium sulphate. The controls therefore differed from the tests simply in the substitution of potassium for the copper.

EXPERIMENT 4.

STARTED FEBRUARY 13, 1906.

Bottle No.	Water		Dextrose (gm.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	Counts				
	Kind	c.c.						Initial	3 Hrs.	6 Hrs.	23 Hrs.	48 Hrs.
1	Best	98	..	0.5	...	10	0.31	540,000	1,800	1,400	660	660
2	"	99	..	1.0	...	20	0.63	540,000	400	100	46	350
3	"	99	1	0.5	...	10	0.31	560,000	415,000	640,000	190,000	4,300
4	"	98	1	1.0	...	20	0.63	500,000	170,000	82,000	100	600
5	Tap	90	..	0.5	...	10	0.31	540,000	134,000	2,000	125	9
6	"	87	..	1.0	...	20	0.63	560,000	6,300	700	15	2
7	Best	98	..	...	1.0	20	....	500,000	......	520,000	95,000	10,000
8	"	98	1	...	1.0	20	....	500,000	......	490,000	200,000	420,000
9	Tap	90	..	...	1.0	20	....	540,000	......	600,000	110,000	1,200

Temperature, 20°–24°.
"Best water" is ammonia-free, distilled water.

EXPERIMENT 5.

STARTED FEBRUARY 15, 1906.

Bottle No.	Water (c.c.)	Dextrose (gm.)	$CuSo_4$ Sol. (c.c.)	K_2So_4 Sol. (c.c.)	Concent. of Salt, (N/1,000,000)	Copper (Parts per Mill.)	Counts			
							Initial	6 Hrs.	24 Hrs.	48 Hrs.
1	100	..	0.5	...	10	0.31	30,000	600	184	40
2	100	..	1.0	...	20	0.63	26,000	200	70	23
3	99	1	0.5	...	10	0.31	26,000	1,300	1,800	900
4	100	1	1.0	...	20	0.63	38,000	contaminated		
5	98	..	...	0.5	10	....	28,000	30,000	14,000	9,000
6	99	..	...	1.0	20	....	30,000	27,000	10,000	.....
7	99	1	...	0.5	10	....	24,000	25,000	12,000	.....
8	98	1	...	1.0	20	....	24,000	21,000	13,000	8,000

Temperature, 22°–24°.

EXPERIMENT 6.

STARTED FEBRUARY 20, 1906.

Bottle No.	Water (c.c.)	$CuSO_4$ Sol. (c.c.)	K_2SO_4 Sol. (c.c.)	Culture	Concent. of Salt (N/1,000,000)	Copper (Parts per Mill.)	Counts	
							Initial	24 Hrs.
1	98	1	..	2,006	20	0.63	44,000	460
2	98	..	1	"	20	....	50,009	49,000
3	99	1	..	A	20	0.63	69,000	600
4	98	..	1	"	20	....	90,000	44,000
5	98	1	..	B	20	0.63	45,000	400
6	97	..	1	"	20	....	48,000	26,000
7	98	1	..	C	20	0.63	61,000	600
8	98	..	1	"	20	....	67,000	25,000

Temperature, 21–23°.

EXPERIMENT 7.

STARTED MARCH 5, 1906.

Bottle No.	Water (c.c.)	Pepton (gm.)	Culture No.	$CuSO_4$ Sol. (c.c.)	Concentration of Salt (N/1,000,000)	Copper (Parts per Mill.)	Counts	
							Initial	24 Hrs.
1	100	0	2,006	0.5	10	0.31	179,000	1,040
2	100	0	"	2.0	40	1.24	189,000	3
3	101	0	A	0.5	10	0.31	2,400	3
4	100	0	"	2.0	40	1.24	2,200	0
5	98	1	2,006	0.5	10	0.31	171,000	2,420,000
6	101	1	"	2.0	40	1.24	175,000	455,000
7	99	1	A	0.5	10	0.31	2,800	19,500
8	98	1	"	2.0	40	1.24	2,900	15,000

Temperature, 20°–24°.

DISCUSSION OF RESULTS.

Effect of organic matter in tap water.—In comparing the results of these experiments, the basis of comparison will be the number of surviving organisms in each case, expressed as percentage of the initial number. Other bases of comparison suggest themselves, but the one selected appears on the whole to be the most logical. In this way the effect of the copper upon those few comparatively resistant organisms, always found in experiments of this nature, is given predominant importance, while the effect upon that large percentage of organisms which is killed in all the experiments has comparatively little weight.

Such a comparison of the average results of Experiments 1 and 3, best water, with those of Experiment 2, tap water, gives the following figures:

Concentration of Copper (*N*/1,000,000)	Per Cent Surviving—24 Hrs.		Ratio ($b \div a$)
	Best Water (a)	Tap Water (b)	
10	0.009	5.800	644
20	0.004	0.280	70
40	0.004	0.053	13
60	0.000	0.000	

It is quite evident that the organic matter present in the tap water inhibits the toxic action of the copper, but the significant fact here is that there is no definite point in the series at which the addition of more copper to the tap water will produce a normal killing effect such as is produced in pure water. The effect of the organic matter cannot be neutralized up to the concentration required for the complete elimination of the organisms. It would appear, therefore, that the apparent inhibition of the toxic effect of the copper is due to the formation of some non-toxic compound; that the formation of this compound is due to a reversible reaction which is complete only at the highest concentration of copper used; and that below this point the addition of increasing amounts of copper simply brings about a further reaction toward this non-toxic compound, producing a new condition of equilibrium according to the law of mass action.

Dextrose.—The effect of dextrose upon the copper sulphate seems to be of a quite different nature. The following figures are calculated from the results of Experiment 4:

Concentration of Copper ($N/1,000,000$)	PER CENT SURVIVING—24 HRS.		Ratio $(a+b)$
	Without Dextrose (a)	With Dextrose (b)	
10	0.12	34.0	283.0
20	0.009	0.02	2.2

In the lower concentration dextrose neutralizes completely the toxicity of the copper, so that the effect is about equal to that in the control (Bottle 8). In the higher concentration the effect of the dextrose is almost nil. This result, taken in connection with the fact that the concentration of the dextrose is about $\frac{1}{18}$ molar, and that there are accordingly over 10,000 $C_6H_{12}O_6$ molecules to each copper ion in the one case and over 5,000 in the other, leads to the conclusion that the results obtained are not due to the formation of a non-toxic compound. A careful study of the electric conductivity of these solutions did not reveal any decrease in the normal conductivity of the copper due to the presence of dextrose. It may be presumed, however, that what has been called a "physiological compound" might be readily broken down under the influence of the electric current.

The following assumption seems to be in agreement with all the facts: The bacteria doubtless attract to themselves by a process of adsorption a certain amount of dextrose, and are thus surrounded by a solution of this sugar more concentrated than that existing in the water. This tends to produce a difference in osmotic pressure between the free solution and this surrounding layer, and it may be that a certain definite concentration of the copper ions is necessary before this film of "osmotic tension" can be pierced. An analogous case is that of surface tension, which presents a certain resistance to the entrance of a non-wetted body.

Peptone.—Peptone was the third substance studied. The results of Experiment 7 show that a 1 per cent solution of peptone allows the typhoid organism to multiply even in the presence of rather strong copper-sulphate solution. Owing to the high electric conductivity of the rather impure peptone, the results of conductivity determinations are uncertain. There seems to be little doubt here, however, that an actual combination has taken place between the copper and the peptone. The addition of sufficient copper solution to the peptone solution to give a distinct color resulted in the formation of a colloidal-like solution, of a robin's-egg blue color.

These results have an important bearing upon many practical points in connection with the use of copper sulphate for the destruction of the typhoid organism. Results obtained in the laboratory in distilled water are not in the least indicative of what may be expected under field conditions. Neither are actual field results on one water reliable criteria for the undertaking of similar work upon another. The impracticability of the internal use of copper sulphate in the treatment of typhoid fever is also suggested by the results obtained with peptone.

Selection of a resistant strain.—Cultures A, B, and C were taken from Bottle 2 in Experiment 5, and had lived for 48 hours in a solution of copper sulphate containing 0.63 parts of copper per million. They were used in Experiments 5 and 6 in parallel with the original strain in order to determine whether they possessed any increased resistance to copper. The results are all negative, indicating that these strains are not more resistant than is the parent strain.

The time factor in the germicidal effect.—In Experiments 1, 3, and 4, where determinations of the numbers of organisms were made at various intervals during the experiment, it is seen that even in the more dilute solution used there is a very rapid falling-off in numbers during the earlier part of the test. In Experiment 1, for instance, the reduction in 5 minutes was 67 per cent in a concentration of 0.38 parts of copper per million, but all the organisms had not been killed in 24 hours. Such results indicate an extreme range of resistance to copper among these organisms. The 42 organisms which survived the treatment for 24 hours lived 288 times as long as the 250,000 which died in less than 5 minutes.

Effect of concentration.—This great variability is also shown in a study of the effect of various concentrations.

The average percentage survival after 24 hours in all experiments with 0.38 parts of copper per million was 0.19; with 0.76 parts, 0.07; with 1.26 parts, 0.04. Notwithstanding the fact that 99.8 per cent are killed by a concentration of 0.38 parts, there are still 0.04 per cent which can withstand the action of a copper solution four times as concentrated.

This tremendous variability is of vital importance, not only in questions of sterilization of water by heat, freezing, or chemicals, in all of which cases such a variability has been shown to exist, but in the far more important questions of the self-purification of streams and the longevity of the typhoid bacillus in the water. Most cases of typhoid fever, contracted from drinking-water, have undoubtedly come from these few resistant forms rather than from those which are known to have perished in the natural stream. A removal of 99.99 per cent of the typhoid organisms may sound like security but actually means high typhoid rates. The importance of this residual hundredth of a per cent cannot be overestimated, owing to the very fact that it is so resistant.

REFERENCES.

BASSETT-SMITH, P. W. *Jour. Prev. Med.*, 1905, 13, p. 388.
ELLMS, J. W. *Jour. N. E. W. W. A.*, 1905, 19, p. 496.
JOHNSON, C. A., AND COPELAND, W. K. *Jour. Infect. Dis.*, 1905, Suppl. No. 1, p. 327.
KRAEMER, H. *Proc. Amer. Phil. Soc.*, 1905, 49, p. 51.
STILES, P. G., AND BEERS, W. H., JR. *Am. Jour. of Physiol.*, 1905, 14, p. 133.
TRUE AND OGLEVEE. *Bot. Gaz.* 1905, 39, p. 1.
SULLIVAN, E. C. *Jour. Am. Chem. Soc.*, 1905, 27, p. 976.

EXPERIMENTS ON THE STORAGE OF TYPHOID INFECTED WATER IN COPPER CANTEENS.

By EARLE B. PHELPS, Boston, Mass.

(United States Geological Survey. Published by Authority of the Director, U. S. Geological Survey.)

EXPERIMENTS ON THE STORAGE OF TYPHOID INFECTED WATER IN COPPER CANTEENS.*

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One of the most striking results of the researches of Moore and Kellerman on the germicidal effect of copper salts on microscopic organisms is the discovery that water brought into contact with metallic copper will dissolve enough of the metal to become distinctly toxic to typhoid and cholera germs. Kraemer and others, following up this line of research, have found that clean copper tanks, or copper strips suspended in water, exert a germicidal action. The use of copper canteens in the army and in other services where water is transported in small quantities naturally suggested itself. The hydrographic branch of the United States Geological Survey before distributing such canteens among its field parties instructed the writer to make an investigation of the whole subject to determine the value of the project. The work has been carried out during the past summer at the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology under the charge of Mr. Marshall O. Leighton, Hydrographer-in-charge of the division of Hydro-economics of the Geological Survey.

The canteens used were of the regular army pattern made entirely of sheet copper, and when full held two quarts of water. The superficial area of copper exposed to the water when the canteen is full is 830 square centimeters or 44 square centimeters per 100 cc. of water. When holding one liter of water, the amount employed in the present experiments, the surface exposed is about 40 square centimeters per 100 cc. These figures are of interest in comparing the present experiments with those of Moore and Kellerman and of Kraemer. Moore exposed surfaces of 40 and 160 square centimeters respectively per 100 cc. of water, while Kraemer used surfaces of about 45 square centimeters per 100 cc.

CULTURES USED.

Three cultures of *B. typhosus* were used as follows:

Culture No. 2001. This culture was obtained from the laboratory of the Boston City Board of Health. It was originally obtained from the

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*(From the Sanitary Research Laboratory and Sewage Experiment Station of the Massachusetts Institute of Technology.)

Massachusetts General Hospital in 1902. It agrees with the ordinary tests for *B. typhosus,* gives the Widal reaction with known typhoid blood, reacts with rabbit serum artificially prepared by inoculation of another culture (No. 2005), and produces in a rabbit a reaction against that other organism.

Culture No. 2005. This culture was obtained in the fall of 1904 from the Boston City Hospital and is in daily use at the laboratory of the Boston Board of Health in Widal tests. It reacts with known typhoid blood, and with rabbit serum prepared by inoculation with culture No. 2001, and produces in a rabbit a reaction against that organism.

Culture No. 2006. This culture was obtained from Dr. J. H. Wright, of the Massachusetts General Hospital. It was taken from the spleen at an autopsy on May 26, 1905. The clinical diagnosis was typhoid fever. The culture according to Wright gives all the tests for *B. tphosus* including the Widal reaction. It reacts in the writer's hand with the artificially prepared sera described above.

METHODS EMPLOYED.

The canteens were cleaned originally by treatment with alkaline potassium permanganate which was allowed to stand in them over night. They were then rinsed in dilute oxalic acid solution and rinsed thoroughly with water. Since the beginning of the experiments they have not been cleaned. In all the experiments here described the mode of procedure was as follows:

An agar culture of the organism to be used was grown for fifteen hours at 37° C. From this culture a suitable dilution in tap water was made. About ten cubic centimeters of this strong water suspension were then added to a liter of non-sterile water, well mixed by shaking, and poured into the canteen. A second liter prepared in exactly the same way was poured into a second canteen and a third similar liter was poured into a glass bottle as a control. The controls were in all cases kept dark by wrapping in dark paper. Duplicate plates were immediately made from all three tests with suitable dilutions. In this way the water was inoculated with from 50,000 to 150,000 organisms per cubic centimeter. The water also was plated out and frequent blank plates were made as a check on the technique. The temperature of the air and of the water was noted. In each series two of the three cultures were used.

The number of organisms remaining in the water at the end of twenty-four hours and, in some cases, at the end of shorter periods was determined by plating on agar. All media used in this work were made according to the methods recommended by the American Public

Health Association. The plates were incubated at 37° for fifteen hours. In counting, the colonies were carefully examined and all colonies which were not typical typhoid colonies were rejected in the count. A number of these colonies which appeared to be typical typhoid colonies were fished from each plate and submitted to the Widal test. For this test I have prepared two rabbits by inoculation with cultures No. 2001 and No. 2005, so that their blood would cause the typical agglutination of the organism. All the colonies fished and tested in this way gave the reaction, thus eliminating all reasonable doubt as to the identity of the organisms in question.

At the conclusion of each experiment the copper dissolved by the water was determined. For this purpose a liter of the water was evaporated to small bulk made acid with sulphuric acid and placed in a platinum dish. The copper was then electrolytically deposited from the solution upon a spiral of platinum wire. In this way the copper was quite completely separated from other dissolved and suspended material of the water with the exception of certain metals which may be deposited with it under such conditions. The deposit was dissolved from the platinum wire in nitric acid, neutralized with ammonia, diluted, and treated with a solution of potassium ferro-cyanide. The resulting color was compared with copper standards prepared in the same way and containing known amounts of copper. A few tests of this method upon known amounts of copper dissolved in tap water indicate that its accuracy for amounts comparable with those found in these studies is within five per cent.

Three series of experiments were carried out. In the first Boston tap water was used, the object being to determine what progressive decrease, if any, would take place in the efficiency of the canteen due to the corrosion or coating over of the surface exposed to the water. Eight successive experiments were made. The effect of shorter time intervals than twenty-four hours was also studied in experiments two and three of this series. The second series consisted of a study of several waters from other localities. These waters were from the Chattahochee at Atlanta, Georgia, the Pecos at Carlsbad, New Mexico, the Colorado at Austin, Texas, and the Milk at Chinook, Montana. One experiment was made on each of the first three waters and two on the Milk River water. The third series of experiments was made on Boston tap water with the canteens which had been used in Series II and which had not been cleaned in the meantime. This set consisted of four experiments, one with each canteen which had been used with the four waters mentioned above. The effect of copper upon the typhoid organisms in Boston water having been quite clearly shown in Series I, no organisms were added in this series. The determinations of copper were made at the end of twenty-four hours.

The results of the first series of experiments are shown in the following tables:

SERIES I. Boston Tap Water.

EXPERIMENT 1. JUNE 8–9.

Canteen.	Culture.	Numbers of *B. typhosus* per cubic centimeter.	
		Initial.	24 hours.
1	2001	100,000	6
		120,000	4
2	2001	130,000	4
		90,000	7
3	2005	140,000	12
		90,000	10
4	2005	100,000	12
		100,000	15
Control			
1	2001	120,000	80,000
		100,000	70,000
2	2005	110,000	40,000
		110,000	60,000

Bacteria in water at start, 25.

Blank 0.

Temperature, Water, 17° C. — 23° C. Air, 22° C. — 28° C.

Copper in water at conclusion, 1.95 parts per million.

EXPERIMENT 2. JUNE 12–14.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.				
		Initial.	Six Hours.	Fifteen Hours.	Twenty-one Hours.	Twenty-four Hours.
1	2001	100,000	75,000	13,000	110	15
		91,000	73,000	14,000	120	12
2	2005	100,000	70,000	10,000	100	8
		100,000	65,000	12,000	70	6
Control						
1	2001	120,000				80,000
2	2005	100,000				90,000

Temperature, Water at start, 18° C. Air, 20°-30°.

Copper in water at conclusion, 1.51 parts per million.

EXPERIMENT 3. JUNE 20–21.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.			
		Initial.	Six Hours.	Eighteen Hours	Twenty-four Hours.
1	2005	110,000	100,000	750	14
2	2005	90,000	80,000	800	17
3	2006	73,000	40,000	340	8
4	2006	70,000	30,000	400	9
Control					
1	2005	100,000			80,000
2	2006	80,000			70,000

Bacteria in city water at start, 14.
Temperature, Water at start, 18° C. Air, 20°-30°.
Copper in water at conclusion, 1.30 parts per million.

EXPERIMENT 4. JUNE 25–26.

Canteen.	Culture.	Number of B. *typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	120,000	0
2	2001	90,000	0
3	2006	160,000	3
4	2006	110,000	2
Control			
1	2001	110,000	70,000
2	2006	130,000	80,000

Bacteria in city water at start, 23.
Temperature, Water at start, 18° C. Air, 28°-32°.
Copper in water at conclusion, 1.2 parts per million.

EXPERIMENT 5. JUNE 30–JULY 1.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	70,000	7
2	2001	70,000	9
3	2006	95,000	4
4	2006	100,000	3
Control			
1	2001	80,000	80,000
2	2006	100,000	90,000

Bacteria in city water at start, 17.
Temperature, Water at start, 20° C. Air, 25°-30°.
Copper in water at conclusion, 1.2 parts per million.

EXPERIMENT 6. SEPT. 1–2.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	83,000	25
2	2001	95,000	32
3	2006	68,000	43
4	2006	73,000	30
Control			
1	2001	90,000	55,000
2	2006	78,000	40,000

Bacteria in city water at start, 14.
Blank, 0.
Temperature, Water at start, 18° C. Air, 28° C.
Copper in water at conclusion, 0.7 parts per million.

EXPERIMENT 7. SEPT. 4-5.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2005	110,000	28
2	2005	115,000	24
3	2006	78,000	40
4	2006	80,000	33
Control			
1	2005	100,000	55,000
2	2006	78,000	48,000

Bacteria in city water at start, 24.
Blank, 0.
Temperature, Water at start, 19° C. Air, 20°-25°.
Copper in water at conclusion, 0.5 parts per million.

EXPERIMENT 8. SEPT. 9-10.

Canteen.	Culture.	Number of *B. typhosus* per cubic centimeter.	
		Initial.	Twenty-four Hours.
1	2001	75,000	24
2	2001	75,000	21
3	2006	95,000	33
4	2006	105,000	36
Control			
1	2001	95,000	43,000
2	2006	90,000	50,000

Bacteria in city water at start, 27.
Blank, 0.
Temperature, Water at start, 20° C. Air, 29° C.
Copper in water at conclusion, 0.5 parts per million.

The results of the first series bring out several points of interest. It will be noticed that in only one case were the organisms reduced to less than one per cubic centimeter. One is, of course, tempted to consider here that the percentage reduction was very great and to reason that if there had been initially only a few organisms present then the elimination would have been complete. Unfortunately we know little of the cause for the great range of variation in the resistance of individual organisms to an unfavorable environment, but it seems probable that such resistances to different kinds of unfavorable environment are more or less correlated so that the organism which is resistant to copper may be the very one which has survived the unfavorable environment of the stream or well. Kraemer found a greater resistance on the part of a typhoid culture grown on agar for 24 hours than with the same culture grown for 15 hours, an observation which has an interesting bearing on this question.

The fact that organisms do survive the copper treatment even in small numbers, seems, in the writer's view, to lessen considerably the value of the canteen as a safeguard against typhoid infection.

A second point of interest is the fact that the efficiency of the canteen decreases as time goes on, probably owing to the accumulation on the surface of the copper of a film of basic carbonate or other insoluble copper compound. The fact that in only eight successive treatments with water the efficiency was seriously reduced indicates that for actual service frequent cleanings of the canteen with acid would be necessary. For this purpose oxalic acid would serve admirably and the cleaning of the canteen might not prove entirely impractical even under field or camp conditions. Between experiments 5 and 6 there was a period of two months during which the canteen stood dry. It will be noticed that a much greater difference is found between the results of these two experiments than between those of any other successive experiments. Plainly the deterioration of the surface goes on in the air as well as under water.

The two experiments in which the time element was varied show that twenty-four hours is the shortest time which should be allowed for anything like a complete removal of the organisms. Although other investigators under laboratory conditions with sterilized water and clean copper plates have found periods of even two hours sufficient to remove completely all typhoid organisms from the water, yet we find that under conditions as nearly as possible like those of actual service a much greater time is necessary and the removal of the organisms is not nearly so satisfactory.

The fact that the three strains of *B. typhosus* used in these experiments gave practically the same results throughout deserves mention. It has already been stated that these cultures have been on artificial media for periods of three years, eight months, and six weeks, respectively. Jackson has found a very marked resistance to copper on the part of freshly isolated cultures, and it might have been expected that a difference would have manifested itself in this case. On the contrary the three cultures acted very much alike, the advantage being first with one and then with another.

The chemical characteristics of the water probably more than any other factor will determine the result of such experiments as these, and differences in the water used doubtless explain very largely the differences in the results obtained by various observers. Especially would it appear that the results obtained by the use of distilled water are not at all comparable with those from natural waters. Moreover, the mere act of sterilizing water by heat may profoundly alter the chemical nature of its impurities and lead to correspondingly abnormal results. The differences noted by Kraemer between waters treated in various ways well illustrated this point, and more recent work by Bassett-Smith illustrated even more forcibly the different results obtained by distilled water and tap water. This matter seemed so important that the second series of experiments was planned in order to learn what effect water of various types would have upon the germicidal action of the copper canteen. The four waters used were collected from various parts of the country, and each is typical of certain peculiar conditions. The turbidity and various forms of hardness and the alkalinity were determined on each water, together with the iron, chloride and sulphate. The results are shown in the following table:

Water.	Turbidity.	Alkalinity. Carbonates and Bicarbonates as $CaCO_3$.	Total Hardness. Calcium and Magnesium as $CaCO_3$.	Carbonates of Sodium and Potassium as Na_2CO_3.	Carbonates of Calcium and Magnesium as $CaCO_3$.	Bicarbonates of Calcium and Magnesium as $CaCO_3$.	Free CO_2.	Iron.	Chorides as Cl.	Sulphates as SO_3.
Milk	0	500	620	0	62	438	0	0	120	380
Pecos	150	150	840	0	0	150	0	0.6	940	1,080
Chattahoochee .	400	9.5	17.5	....	0	0	+	5.2	68	35
Colorado	110	137	127	11	5	122	0	0.4	3	0

The water of the Milk River was free from turbidity, but carried a large amount of alkaline earth bi-carbonates, and little calcium or magnesium in any other form. That of the Pecos had a much smaller carbonate or bi-carbonate content, also due wholly to the alkaline earths, but was very high in the so-called incrustants — other salts of calcium and magnesium; its turbidity also was low. The Chattahoochee was very turbid water with no incrustants and a very low alkalinity. The Colorado carried some turbidity together with a moderate hardness due entirely to bi-carbonates — that is, without incrustants; there were present also in this water about ten parts per million of alkaline carbonates.

The results of the five experiments made with these waters are shown in the following tables:

SERIES II. HARD AND TURBID WATERS.

EXPERIMENT 1. JULY 26.

Milk River Water. Culture 2001.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	95,000	80,000
2	100,000	83,000
Control 1	100,000	70,000

Bacteria in water at start, 54.
Same after twenty-four hours in canteen, 40.
Temperature, Water at start, 28° C. Air, 30°.
Copper in water at conclusion, 0.2 parts per million.

EXPERIMENT 2. JULY 26.

Chattahoochee River Water. Culture 2001.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	120,000	50
2	120,000	40
Control		
1	110,000	80,000

Bacteria in water at start, 550.
Same after twenty-four hours in canteen, 500.
Temperature, Water at start, 28° C. Air, 30°.
Copper in water at conclusion, 1.5 parts.

EXPERIMENT 3. AUG. 18–19.

Milk River Water. Culture 2006.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	100,000	780
2	100,000	920
Control		
1	110,000	70,000

Bacteria in water at start, 50.
Same after twenty-four hours in canteen, 54.
Temperature, Water at start, 26° C. Air, 26°.
Copper in water at conclusion, 0.3 parts per million.

EXPERIMENT 4. AUG. 18–19.

Pecos River Water. Culture 2006.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four Hours.
1	110,000	100
2	100,000	140
Control		
1	100,000	100,000

Bacteria in water at start, 70.
Same after twenty-four hours in canteen, 50.
Temperature, Water at start, 26° C. Air, 26°.
Copper in water at conclusion, 0.5 parts per million.

EXPERIMENT 5. AUG. 18–19.

Colorado River Water. Culture 2006.

Canteen.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-one Hours.
1	105,000	8
2	100,000	2
Control		
1	130,000	60,000

Bacteria in water at start, 75.
Same after twenty-four hours in canteen, 51.
Temperature, Water at start, 26° C. Air, 26°.
Copper in water at conclusion, 1.6 per million.

TABLE OF AVERAGE RESULTS.

Water.	Numbers of *B. typhosus* per cubic centimeter.	
	Initial.	Twenty-four hours.
Boston	90,000	20
Milk River	99,000	45,000
Pecos	105,000	120
Chattahoochee	120,000	45
Colorado	103,000	5

Comparing the results of experiments 1 and 4, Milk and Pecos rivers, it will be seen that the Milk River water prevented to a marked degree the toxic action of the copper, while the results with the Pecos water indicate a much greater toxicity. The amount of copper dissolved by the Milk water was 0.2 parts per million, and by the Pecos 0.5 parts. The total hardness of the Pecos water was the greater, but it was due largely to the incrustants, while the hardness of the Milk water was due to bi-carbonates entirely. It appears, therefore, that carbonates and bi-carbonates prevent the solution of the copper and consequently destroy the efficiency of the canteen to a much more marked degree than do the incrustants.

The Colorado water with some turbidity and a moderate hardness dissolved as much copper and showed as marked a toxic effect as the Boston water would have done under the same circumstances. This water is characterized by the presence of sodium or potassium carbonate equivalent, to about ten parts per million of calcium carbonate. There can be little doubt but that the amount of copper dissolved in this case was due to these alkaline carbonates which dissolved the copper by the formation of soluble double salts. The Chattahoochee dissolved about the same amount of copper as did the Colorado, but the toxic effect was much less. This, I believe to be due to the fact recently pointed out by Sullivan, that mixtures of copper salts and such insoluble silicates as kaolin obey the mass action law in that alkaline and alkaline earth salts are dissolved from the silicates and complex insoluble silicates of copper are precipitated until an equilibrium is established. This equilibrium point Sullivan found to vary with variable conditions, especially according to the character of the silicate and its fineness. In some cases practically all the copper was deposited, in others about one-half. This observation is not only of interest in connection with the special problem under discussion, but it has a broad bearing upon the whole subject of the treatment of water with copper salts. Obviously if this reaction takes place speedily, the effect of such salts upon the organisms of the water will be neutralized to a large extent. Neither must the fact be overlooked that calcium and magnesium sulphates will often be the product of such a reaction, the permanent hardness of the water being thereby increased.

It may be stated, therefore, as the result of this series of experiments, that the copper canteen is totally inefficient in the presence of any considerable amounts of carbonates and bi-carbonates of the alkaline earths, but that the sulphates and chlorides of these metals exert a much less antagonistic effect. The presence of carbonates of the alkalies apparently assists in the solution of copper, and therefore increases the toxic action of the canteen. Turbidities due to clay or other silicates tend to precipitate rapidly, and sometimes completely, all dissolved copper as insoluble silicate, and hence destroy the toxic effect.

The absence of any solvent action upon the copper by the Milk River water may be explained in two ways. Either the chemical nature of the water precludes the solution of copper or the solution commences but is stopped by the formation of an insoluble precipitate upon the copper surface. In order to study this point Series III was undertaken, in which each of the four canteens used in Series II were filled with Boston tap water and allowed to stand for 24 hours. The results are given in the following table:

SERIES III. EFFECT OF HARD AND TURBID WATERS ON COPPER CANTEENS.

Experiment 1. Boston water.

Canteen.	Previously held water from.	Copper dissolved in 24 hrs. Parts per million.
1	Milk River	0.2
2	Pecos River	0.3
3	Cataahoochee River	1.0
4	Colorado River	1.3

It appears, therefore, that the alkaline waters do coat the copper surface, and that the coating protects the copper against further solvent action by soft waters, but that turbid soft waters do not thus coat the surface. They prevent the toxic action of the canteen merely by precipitating the copper as silicate after it has been dissolved. The canteen which had contained the Milk River water was opened and examined at the conclusion of the experiments. As we had anticipated the surface was found to be dark covered and heavily tarnished.

In conclusion, the principal points of interest may be summed up as follows:

1. Storage of typhoid infected Boston city water in clean copper canteens for twenty-four hours results in the destruction of the great majority of the infecting organisms. The elimination, however, is seldom complete. Any shorter period of storage is insufficient. It is quite possible that the surviving germs are the ones that would naturally have survived other unfavorable conditions in the stream or well, and hence are the ones against which protection would have been most needed.

2. Clean copper canteens become tarnished with continued use, and even on standing dry, and their efficiency as disinfecting agents becomes materially reduced thereby. They may readily be cleaned with acid.

3. Cultures which have been on artificial media for three years, eight months and six weeks, respectively, gave practically identical results throughout this work.

4. The chemical nature of the water is the determining factor upon which the results depend. Boston city water, a soft, colored surface water, prevents to a large degree the extreme toxic effect noted by some observers in the case of distilled and other waters. Carbonate and bi-carbonate of calcium and magnesium, as well as high turbidity, may completely destroy the toxic action of the canteen, the former by coating the surface and the latter by precipitating out the dissolved copper; moreover, in the former case the surface of the canteen is rendered useless for the further disinfection of even soft waters without cleaning.

It seems, therefore, that the copper canteen can claim a place only as a useful factor of safety and not in any way as a substitute for more effective means of preventing infection. It is a serious question whether or not its use would not give a false sense of security, bring about carelessness in the selection or protection of a water supply or in the handling of the water, and indirectly lead to the use of a typhoid infected water against which the canteen itself might be found to be an entirely inadequate protection.

REFERENCES.

Bassett-Smith, P. W.— Experiments to Demonstrate the Germicidal Power of Copper and Copper Salts on Pathogenic and Non-pathogenic Organisms. The Journal of Preventive Medicine, XIII, '05, 388.

Kraemer, Henry.— The Copper Treatment of Water. American Journal of Pharmacy, 76, '04, 574.

— The Oligodynamic Properties of Copper Foil on Certain Intestinal Organisms. Proceedings of the American Philosophical Society, XLIX, '05, 51.

Moore, G. T. and Kellerman, K. F.— A Method of Destroying or Preventing the Growth of Algae and Certain Pathogenic Bacteria in Water Supplies. U. S. Department of Agriculture, Bureau of Plant Industry, Bull. 64, 1904.

— Copper as an Algicide and Disinfectant in Water Supplies. U. S. Department of Agriculture, Bureau of Plant Industry, Bull. 76, 1905.

Sullivan, E. C.— The Chemistry of Ore Deposition — Precipitation of Copper by Natural Silicates. Journal American Chemical Society, XXVII, '05, 976.

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